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DCAS-TN-61-3  
VOL II, PART I, NO. 5

63-4-2

REPORT NO.  
TDR-930 (2701-01) TN-1  
VOL II, PART I, NO. 5

CATALOGED BY DDC  
AS AD No. 409902

Applied Research Programs  
Abstract Bulletin  
FLIGHT VEHICLE POWER and MATERIALS

Volume II (Part I)

*Abstracts 2-399 through 2-518*

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JANUARY, FEBRUARY, MARCH 1963

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*Prepared for* COMMANDER SPACE SYSTEMS DIVISION

UNITED STATES AIR FORCE

*Inglewood, California*



409 902

AEROSPACE CORPORATION  
CONTRACT NO. AF 04 (647)-930

DCAS-TN-61-3  
Vol. II, Part I, No. 5

Report No.  
TDR- 930(2701-01)TN-1  
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Literature Research Group  
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AEROSPACE CORPORATION  
El Segundo, California

January, February, March 1963

Contract Nos.  
AF 04(647)-930  
AF 04(695)-169

Prepared for  
COMMANDER SPACE SYSTEMS DIVISION  
UNITED STATES AIR FORCE  
Inglewood, California

### ABSTRACT

This Bulletin contains abstracts of the unclassified literature on the subject of Flight Vehicle Power (USAF Applied Research Area 750F). The following categories are: (1) Chemical Sources of Energy; (2) Magnetohydrodynamic Systems; (3) Mechanical Devices; (4) Nuclear Sources of Energy; (5) Solar Sources of Energy; (6) Thermionic Devices; (7) Thermoelectric Devices. Abstracts of selected references in the field of materials are also included. All abstracts are prepared from the original reports and are limited to those available within Aerospace Corporation. References appended to the abstracts are those referring to report literature only; papers published in technical journals and other readily available sources have not been cited.

Approved by:

K. B. Andrews  
K. B. Andrews  
Supervisor  
Literature Research Group

AEROSPACE CORPORATION  
El Segundo, California

## PREFACE

This Bulletin contains abstracts of the unclassified literature on the subject of Flight Vehicle Power (USAF Applied Research Area 750). Abstracts of selected references in the field of materials are also included. All abstracts are prepared from the original reports and are limited to those available within Aerospace Corporation. Aerospace Corporation is not able to furnish copies of the abstracted reports to requesters outside the corporation. It is suggested that persons wishing to obtain such reports contact the originator.

## ACKNOWLEDGEMENT

The information included in this volume was prepared by K. B. Andrews, N. B. Crow, R. C. Evans, M. S. Hicks, E. Moore, E. H. Smith, and K. N. Tirogoff.

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AF 33(657)-9820, 2-442
- Westinghouse Electric Corp.,  
Lima, Ohio  
AF 33(657)-8089, 2-479

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Westinghouse Research Labs.,  
Pittsburgh  
AF 33(616)-7157, 2-500

Wright-Patterson AFB, Ohio  
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Wyandotte Chemicals Corp.,  
Wyandotte, Michigan  
AF 33(657)-9174, 2-505

I. FLIGHT VEHICLE POWER

## SECTION A - GENERAL

- 2-399 DEVELOPMENT OF AN ION ROCKET ENGINE SYSTEM FOR ATTITUDE CONTROL AND STATION KEEPING. Quarterly Progress Report No. 2, 1 Jan.-31 Mar. 1963. Hughes Research Labs. Div., Hughes Aircraft Co., Malibu, Calif. Apr. 1963. 70p. illus. Contract: NAS 3-2510. 2 refs. A63-4971.

The Ion Rocket Engine System being developed under this contract is intended for ultimate application to three axis attitude control and station keeping of a synchronous satellite. Attitude control is exercised by linear strip ion engines producing 0.5 mlb of thrust perpendicular to the reference axis at the end of a moment arm. Station keeping is provided by annular strip ion engines producing 1.5 mlb of thrust through the center of gravity of the satellite. Some of the major accomplishments during this quarter were: (1) Electrical and thermal testing of a development model annular strip engine with performance very close to the design specifications for the satellite control system; (2) Construction and electrical testing of the first attitude control linear strip engine; (3) Construction and preliminary thermal testing of the first high efficiency (low mass) ionizer for the linear strip engine; (4) Successful vibration testing of an annular strip engine; (5) Completion of a single axis linear strip engine power control circuit breadboard; (6) Packaging of the single axis attitude control electronics; (7) Assembly of the development model engine positioner; (8) Definition of sensor subsystem requirements for the SERT-III and synchronous orbit missions; (9) Issuance of R.F.P.'s for earth sensors; (10) Preparation of detailed system block diagram; and (11) Preparation of procedures to implement the reliability/quality assurance program.

References

1. Quarterly Progress Report No. 1, Contract NAS 3-2510, January 28, 1963, pp. 48-53.

- 2-400      MOLECULAR CIRCUIT DEVELOPMENT. Charles W. Moulton.  
Eleventh Quarterly Report, 15 Nov. 1962-15 Feb. 1963.  
Melpar, Inc., Sub. of Westinghouse Air Brake Co.,  
Falls Church, Va. 61p. illus. Contract: NOW 60-0362-c.  
A63-2500.

The ultimate purpose of this program is to provide research and development in materials and techniques suitable for formation of molecular circuits. Exploratory work was carried out this quarter on circuits utilizing field effect devices. The lack of high-temperature dielectric materials is not delaying the program. Because of the requirements for high-temperature, emphasis on both sputtering and pyrolytic film formation is being placed currently on silicon carbide. The conditions for obtaining either uniform films or crystallites were established. It was found that silicon crystallites of several mils in diameter could be reproducibly obtained, while crystallites of up to 20 mils in diameter could be formed on occasion. Studies of germanium films formed in an ultrahigh vacuum chamber have led, within experimental limits, to the conclusion that background pressure during deposition does not have a significant effect on the film properties. The oxides of neodymium and hafnium are now being investigated for use as high-temperature, thin-film dielectrics.

- 2-401      16TH ANNUAL POWER SOURCES CONFERENCE,  
PROCEEDINGS. (Formerly called The Battery Research  
and Development Conference). Sponsored by U. S. Army  
Signal Research and Development Laboratory, Power  
Sources Div., Fort Monmouth, N. J., held 22-24 May 1962.  
178p. illus. Refs.      QC603 U58.

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Metallic Electrodes for  $H_2$ - $O_2$  Fuel Cells, by J. C. Duddy,  
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 $H_2$  and  $O_2$  Electrodes for Acid Media, by Walter G. Taschek and  
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Solid Electrolyte Fuel Cells, by D. H. Archer and E. F. Sverdrup  
Radioactive Regenerative Fuel Cells, by J. F. Yeager,  
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Overload Protection in Solid State Power Supplies, by J. L. Jensen  
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2-402      STATIC ENERGY CONVERSION STUDIES. J. Colwell and  
R. L. Palmer. Second Quarterly Technical Progress Report,  
18 Aug. -17 Nov. 1962. General Dynamics/ General Atomic,  
San Diego, John Jay Hopkins Lab. for Pure and Applied  
Science, Rept. no. GACD-3705. 30 Nov. 1962. 19p. illus.  
Contract: AF 33(657)-9203, Proj. 8173, Task 817302-14.  
10 refs.      A63-403.

Numerous studies were undertaken to see what efficiency might be expected from a material such as InSb or HgTe which has a large ratio of electron to hole mass. HgTe was selected as one material on which to perform measurements. The general characteristics which the optimum material should have were decided upon and the optimum geometrical shape and optimum temperature gradient were selected. Experimental investigation was begun with the measurement of the Nernst coefficient.

References

1. J. Colwell, First Quarterly Report, May 17, 1962 through August 31, 1962, on Contract AF 33(657)-9203, Project No. 8173, Task 817302-14, General Atomic Report No. GACD-3474, (1962).

- ( ) 2-403 STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR  
POWER SOURCE FOR FIVE-WATT U. S. COAST GUARD  
LIGHT BUOY. Martin Marietta Corp., Nuclear Div.,  
Baltimore, Final Report, MND-P-2720. 2 Feb. 1962.  
130p. illus. Contract: AT(30-3)-217. 11 refs.  
A63-1717.

The objectives of the SNAP 7A program were to design, manufacture, test and deliver a five-watt electric generation system for a U. S. Coast Guard 8 x 26E light buoy. This report describes the 10-watt Sr-90 thermoelectric generator, the dc-to-dc converter, batteries and the method of installation in the light buoy. The SNAP 7A generator was fueled with four capsules containing a total of 40,800 curies of Strontium-90 titanate. The generator was fueled at the Martin Marietta hot cell facility located in Quehanna, Pennsylvania. After fueling and testing, the SNAP 7A electric generating system was installed in the Coast Guard light buoy at Baltimore, Maryland, on December 15, 1961. Operation of the buoy lamp has been continuous since that time.  
(Author)

References

1. "Final Safety Analysis, SNAP 7A Generator," MND-P-2614,  
The Martin Company, 1961.

- ( ) 2-404 THERMAL RADIATION GUIDES FOR POWER TRANSMISSION.  
W. J. Swenson. Period covered: 1 Oct. -31 Dec. 1962.  
Electro-Optical Systems, Inc., Pasadena, Rept. no. 3000-Q-3.  
15 Jan. 1963. 48p. illus. Contract: AF 33(657)-8526,  
Proj. 8128, Task 61083. A63-1639.

This technical progress report describes research on the transmission of radiant energy through a hollow, reflective tube from a heat source to another location in a spacecraft without intermediate Carnot cycle conversion equipment. A thermodynamic analysis has been completed. Using a computer program, the thermal balance of any design can be evaluated readily. A few general comments for the designer are made. The influence of conduction can reduce peak guide temperatures between 25 and 50% for reasonable wall thicknesses. An examination of the basic difference equations indicates that the parabolic concentrator and guide dimensions may be scaled up or down if the ratio of their focal lengths remains constant and if the ratio of conductivity and the square of conductor focal length also stays constant. The results of the analysis are presented as a set of curves. This analysis has indicated a suitable configuration and set of guide dimensions for a thermal radiation guide which should operate at reasonable temperatures during solar testing. One test made during the period verifies the thermodynamic analysis. Guide efficiency during this test was 70%. The analysis has shown that it is extremely difficult to calculate with precision the reradiation energy from the absorber coupled to the wave guide. The major effort here must be made experimentally, and an experiment is being devised

2-404 (Continued)

for this purpose. Fabrication techniques are being developed for the system. The guide, to be 6 in. in diameter, is to be constructed of longitudinal segments of copper with a thin coating of highly polished, electroformed nickel. Spin casting is to be used for forming concentrator mandrels; the concentrators are to be electroformed over these. Methods for making right angle guides are being considered.

2-405 WEIGHT OPTIMIZATION OF A SOLAR OR NUCLEAR  
MECHANICAL CONVERSION SYSTEM. Leon Schipper.  
Wright Air Development Center, Aeronautical Assessories Lab.,  
Wright-Patterson AFB, Ohio, WADC-TN-59-180. June 1959.  
50p. illus. Proj. 3145. 4 refs. A63-2064.

The purpose of this study is to determine the extent to which increase in cycle efficiency is warranted to optimize the weight of solar- or nuclear-powered conversion systems. The first section of this report deals with establishing the basic parameters (overall efficiency, cycle efficiency, cycle deviation, specific collector and radiator areas, energy storage, specific system weight, and cycle temperature), selecting specific values for some parameters, and noting the effect on specific system weight by varying the remainder. The second section separates the basic parameters into two major groups, the power producing and the heat-rejecting, and provides a means for determining minimum specific system weight by properly matching the two groups. The solar-powered system in general consists of three units: a collector unit, a conversion unit, and a heat-rejection unit or radiator. The variables contributing most to system size and weight are collector and radiator. A nuclear-powered system in general consists of four units: a reactor unit, a conversion unit, a shielding unit, and a heat rejection unit or radiator. For this system, the radiator provides the only possibility for significantly reducing weight.

GENERAL - CITATIONS ONLY

HEATING AND COOLING SERVICES FOR THERMALIBRIUM ENSEMBLE.  
Volume I. Development Planning Study and Experimental Development.  
J. R. Wilson and J. R. Hamm. Westinghouse Electric Corp., Pittsburgh,  
Final Report, no. 9160-01206-906(1). 3 Oct. 1960. 80p. illus. Contract:  
DA 19-129-QM-1480 (01-5003), Proj. 7-93-30-3001. A63-3980, vol. 1.

HEATING AND COOLING SERVICES FOR THERMALIBRIUM ENSEMBLE.  
Volume II. Feasibility Study. Westinghouse Electric Corp., Pittsburgh,  
Final Report, no. 9160-01206-906(2). 3 Oct. 1960. 169p. illus.  
Contract: DA 19-129-QM-1480 (01-5003), Proj. 7-93-30-3001.  
A63-3980, vol. 2.

HEATING AND COOLING SERVICES FOR THERMALIBRIUM ENSEMBLE.  
Volume III. Construction of Heating Units. W. D. Pouchot. Westinghouse  
Electric Corp., Pittsburgh, Final Report, no. 9160-01206-906(3). 3 Oct.  
1961. 38p. illus. Contract: DA 19-129-QM-1480 (015003), Proj.  
7-93-30-001. A63-3980, vol. 3.

HIGH CURRENT SUPERCONDUCTIVITY. S. Bozowski, J. I. Gittleman,  
R. H. Parmenter, B. Rosenblum, F. D. Rosi, T. E. Seidel, and  
A. W. Wicklund. Semiannual Technical Report no. 2, 1 Jan.-30 June 1962.  
Radio Corp. of America, RCA Labs., Princeton, N. J. 32p. illus.  
Contract: DA-36-039-SC-88959, Proj. 9800, ARPA order no. 210-61.  
15 refs. AD 283 322. A63-2299.

THE MAGNETIC INDUCTION PLASMA ENGINE. Milton U. Clauser.  
Space Technology Labs., Inc., Physical Research Lab., Los Angeles,  
STL/TR-60-0000-00263. 19 Aug. 1960. 37p. illus. No contract no.  
14 refs. A63-1833.

MICROWAVE ENERGY CONVERSION. E. M. Sabbagh. Period covered:  
Jan.-July 1961. (The study period from July 1960 - Jan. 1961 is covered  
in WADD TR 61-48, Part I). Purdue Univ., Lafayette, Indiana, Final  
Report, WADD-TR-61-48, Part III. Sept. 1962. 137p. illus. Contract:  
AF 33(616)-7355, Proj. 3145, Task 61098. 14 refs. A62-1179, pt. 3.

POWER CONVERSION WITH NONLINEAR REACTANCES. Edward Della  
Torre and Murray D. Sirkis. Rutgers Univ., New Brunswick, N. J.,  
College of Engineering, Rept. no. 59-1; AFOSR-TN-59-596. June 1959.  
12p. illus. Contract: AF 49(638)-554. 10 refs. A63-2020.

SECTION B - CHEMICAL SOURCES OF ENERGY

- 2-406 ALKALINE BATTERY EVALUATION. W. W. Clark, W. G. Ingling, I. F. Luke, and R. Leaf. Fourth Semiannual Report, 15 Apr. -1 Sept. 1962. Cook Electric Co., Inland Testing Labs., Dayton, Final Report, ASD-TDR-62-893, Part I. (This report supersedes ASD-TDR-62-553, dated June 1962, ASD-TDR-62-68, and ASD-TR-61-236). Oct. 1962. 146p. illus. Contract: AF 33(616)-7529, Proj. 8173, Task 817304-9. 5 refs. A62-12426, pt. 1.

This report covers the first four periods of an alkaline battery applied research and failure analysis program. The purpose of this program is to establish a broad base of battery test data for use in the design of the electrical system of future space vehicles and to determine the actual failure mechanism of all new battery systems under varying environmental and cycle-life conditions so that improved space batteries can be developed. Another objective is to determine techniques and/or materials to prevent these failures, while at the same time increase the usable watt-hours-per-pound capability and cycle life of the battery. The program includes an evaluation of one type 12 ampere-hour nickel-cadmium, one type of 15-ampere-hour silver-zinc sealed cells, in addition to an evaluation of one type of 20 ampere-hour nickel-cadmium cells. To date, cycle-life tests have been conducted on the 12 ampere-hour sealed nickel-cadmium cells in four temperature environments and four depths of discharge, in groups of 10 cells and in batteries of 20 cells. Cycle-life tests have been completed on one eight-cell group of the silver-zinc cells subjected to 25 percent discharges at 25°C in a 2-hour cycle period, and are currently in progress on several other groups of the same type of silver-zinc cells as well as on the silver-cadmium cells. The results of cycle-life tests on the 12-ampere-hour nickel-cadmium cells show that: (1) Cell cycle-life with shallow discharges is considerably longer than cycle-life at deep discharges and (2) Cycle-life is reduced by high and low ambient temperature. (Author)

- 2-407 CHEMICALLY HEATED ZINC SILVER OXIDE BATTERY. Joseph J. Holechek, Paul E. Streigle, Robert A. Giovanelli, J. B. Randolph Carroll, and Henry W. Mattheu. First Quarterly Progress Report, 1 July-30 Sept. 1962. Catalyst Research Corp., Baltimore, Report no. 1. 27p. illus. Contract: DA-36-039-SC-90812, Proj. 3A99-09-002. 8 refs. A63-3255.

The ultimate objective of this project is the development of an automatic heating and activation system to initiate the standard BA-485/U battery in less than 1.5 seconds throughout the range of -40°F to 165°F while maintaining close voltage regulation. Specifically, a heat exchanger is to be designed to permit the rapid heating of the battery electrolyte during its

2-407 (Continued)

injection into the cell block. The anticipated activation system will consist of an electrolyte reservoir, a gas generator, and the heat exchanger device. The standard BA-485/U cell block will be modified in an attempt to improve electrolyte distribution to the electrodes and thus improve the rate of activation. The design of each of these major components will significantly influence battery performance, activation, and operation. A study was undertaken to determine the theoretical heat requirements to promote rapid activation, particularly at the  $-40^{\circ}\text{F}$  ambient temperature. On the basis of data from a previous study, the investigators established that about 75% of a total 300 cc was ejected from the standard BA-472/U reservoir. This volume was found to be sufficient to operate the standard unit. Approximately 75% of a total of 350 cc was ejected and found sufficient to operate the chemically heated version of the BA-472/U. The increased volume was required to supply additional heat to the battery. Total heat requirements for the major components of the cell (zinc, silver oxide and copper grid) were determined theoretically from available enthalpy data. The required temperature rise was assumed to be  $117^{\circ}\text{F}$ , from  $-40^{\circ}\text{F}$  to  $77^{\circ}\text{F}$ . The total requirement was 41,290 calories. Theoretical determinations of the heat requirement of the electrolyte (31% KOH) to raise the complete cell to an operating temperature of  $77^{\circ}\text{F}$  indicated that the electrolyte must be raised to a temperature of  $122^{\circ}\text{F}$ . As a result of the theoretical findings, the surface area of the heat exchanger was determined to be approximately  $215\text{ in}^2$ . Two prototype heat exchanger designs were based on the use of 1 inch wide,  $1/16$  inch thick copper channeling. The first design was composed of four  $27 \times 1 \times 1/16$  inch channels in parallel which would provide  $216\text{ in}^2$  of heating surface and an estimated flow rate of 808 cc per second. In the event that this system does not produce adequate flow rate a second or dual heat exchanger system has been designed.

#### References

1. Holechek, J. J.; Streigle, P. E.; et al. "Automatically Activated Zinc-Silver Oxide Battery" Final Report, Contract DA-36-039-SC-85361, 1 July 1960 to 30 June 1962.

2-408 DESIGN OF HYDROGEN-OXYGEN CAPILLARY TYPE FUEL CELL. N. P. Bannerton, R. Chesner, L. E. Donelan, E. L. Laskey and J. C. Prestridge. Third Quarterly Technical Progress Report, 1 Nov. 1962-31 Jan. 1963. Allis-Chalmers Mfg. Co., Milwaukee. 15 Feb. 1963. 23p. illus. Contract: AF 33(657)-8970, Proj. 8173, Task 817303. A63-2666.

This report describes the hardware development of a fuel cell power unit for a space vehicle. Tests on two samples are described, component sources are identified, and temperature control requirements of the unit are analysed. Finally, interface problems with the vehicle are outlined.

2-409      ENGINEERING RESEARCH STUDY OF FUEL CELL POWER  
PACK. Phase II Report. R. Drushella and R. Susnar.  
Period covered: 1 July 1962-31 Jan. 1963. Allis-Chalmers  
Mfg. Co., Milwaukee. 28 Feb. 1963. 52p. Contract:  
DA-49-186-502-ORD-1057. A63-4406.

A hydrogen-oxygen 1.5 KW fuel cell power pack was built utilizing the fuel cell state of the art at the initiation of the contract. An evaluation of the power pack was made with respect to operational characteristics and operational life as influenced by environmental and operational conditions. Material and energy balances were made on the power pack. The purpose of the evaluation was to isolate and define system engineering research problems. The tests conducted show that the fuel cell power pack operated satisfactorily under various conditions. The degree of successful testing was directly related to the reliability of the supporting subsystems and their components. Testing was rarely impeded by the fuel cells themselves. The fuel cells dissipated all of their waste heat to the surrounding atmosphere under all of the test conditions. In the course of dissipating this waste heat, they were also able to maintain an even surface temperature as well as an even temperature throughout the module. The testing at ambient, reduced, and elevated temperature showed that a variable environmental temperature of 14°F to 125°F has no apparent effect on the fuel cells or the reactions occurring in them. However, the subsystem and its components are definitely affected. The materials balance and efficiency studies have shown that the current efficiency is 98.5 percent. If a system of this type is to operate at temperatures lower than about 20°F, further steps will have to be taken to conserve the waste heat from the fuel cells. The basic problem areas with the system were the hydrogen recirculation pump and the moisture control mechanisms and its related valving. The hydrogen recirculation pump used was a diaphragm type. This pump did not have a sufficient capacity and was inefficient. The control mechanism, as employed in this application, has four inherent characteristics that make it less than satisfactory for this type of application. The basic principle upon which this mechanism operates is that for any given load, the relationship between the moisture content of the cell and its voltage be repeatable. It requires that the voltage limits, between which the solenoids operate, be manually adjusted for every large change in load applied to the fuel cell. Also, it requires that the valves regulating the rate of hydrogen passing through the cell be manually adjusted with a large change in load on the cells. Time, service, and storage at environmental temperature of 14° to 125°F have little or no effect on the open circuit voltage of the cells. The complexity of this system indicates that a more compact system with a less complex mode of operation be developed. Rather than spend the effort and time required to develop reliable components, it seems far more logical to develop a fuel cell system which doesn't require a massive or complex subsystem. Such a system would not require a recirculation system or a voltage regulated purge control for moisture removal. It would, in fact, be a static system. An alternative of this would be a system which would have a continuous recirculation of gas through the fuel cell.



( ) 2-410 FINAL REPORT, NASA CONTRACT NAS5-1607.  
D. B. Colbeck. Electric Storage Battery Co., Raleigh,  
North Carolina, Rept. no. E-6-63, 21 Mar. 1963.  
47p. illus. A63-3669.

Experimental work resolving the effects of plate thickness, sealing techniques, and various separator systems led to the design of a standard line of non-magnetic, sealed, low rate silver-oxide-zinc cells for space applications. Experimental cells of six types, differing in positive plate thickness (0.146, 0.092, and 0.064 inch) and positive plate fabrication technique (pressed powder and ESB proprietary dispersed plastic process), were tested at all combinations of three discharge rates (10, 50, and 100-hour rates) and three discharge temperatures (10, 25, and 50°C). Cells containing 0.064 inch thick dispersed plastic positives provided the highest combination of energy density (watt-hours per pound and per cubic inch) and efficiency (ampere-hours per grams of silver). Dispersed plastic positive plates with thicknesses in the order of 0.064 inch were incorporated into qualification cell designs. Separator material tests and separator system evaluation in cells stored charged at 71°C revealed that, of all combinations studied, the following provided the best capacity loss protection coupled with minimum space requirement: (a) 1 layer of ESB-Reeves White Synpor and 5 layers of 193 PUD-O Cellophane; (b) 1 layer of Dynel EM-403, 1 layer of Polypor WA and 5 layers of 193 PUD-O Cellophane. System (a) was used in Model 216 and 217 qualification cells, while Model 218 units contained system (b), modified by the addition of one extra layer of cellophane. Data from 30 deep discharge cycles on high rate test cells show that dry polyvinyl alcohol powder, incorporated into the negative plate mix, acts as a satisfactory binder. Test cells devoid of free electrolyte and half filled with electrolyte delivered higher capacity with lower cell operating pressures than those flooded with electrolyte. The "dry" condition was selected for the qualification lot cells to minimize weight. Burst pressure tests on the light weight plastic cell cases indicated pressures as high as 90 psig can be sustained with no damage. Operating pressures measured during development tests did not exceed 20 psig except when overcharged at constant current to 2.1 volts or over-discharged beyond cell reversal. Addition of silicon dioxide "Eccospheres" to epoxy sealing resin results in a cell case seal of equal reliability to that of the resin alone, with a 30-40 percent saving in weight. This "filled" resin was used for the final seal on qualification lot cells. Charged stand capacity loss rates of 15.0, 3.2, and 2.9 percent per month at 50, 32, and 10°C, respectively, have been observed to date in experimental cell tests. Additional results, derived from cells currently in long term storage at 10°C, are expected to change the average capacity loss percentage at that temperature to a value below the 2.9 percent per month shown above. Results obtained to date indicate that three cells meet or exceed all contract objectives with the sole exception of having initial discharge voltages above desirable levels.

- 2-411 IN-HOUSE BATTERY SEPARATOR INVESTIGATION.  
Edward L. Harris. Aeronautical Systems Div.,  
Wright-Patterson AFB, Ohio, ASRMFP TM 63-21.  
11 Mar. 1963. 11p. Proj. 8173, Task 817304-12.  
A63-4488.

The purpose of this in-house investigation is to perform exploratory research and experimental study which will lead to better screening methods for long-life, alkali separator materials for the silver-zinc secondary battery. This report discusses a method for screening possible separator materials on the basis of ionic diffusion through separator membranes. Fibrous sausage casing designated as F.S.C. is used as a preliminary standard to establish a "yardstick" for testing other membranes. The results obtained from experimental data with the one-half inch and one inch orifices containing samples of F.S.C. and cellophane show a reproducibility of results with different size orifices for the same material which indicates the technique can be regarded as reliable. The apparatus used for measurement of diffusion of hydroxyl ions through membranes provided several desirable features: (1) mechanical stirring, (2) different size orifice plates for inserting membranes before placing the plate in the apparatus, and (3) direct measurement of ion change without removal of samples from the reaction chamber. A detailed description of the procedure and graphs of the test results are included in this report.

- 2-412 INVESTIGATIVE STUDY RELATING TO FUEL CELLS.  
Progress Report no. 9, 1 Sept.-31 Dec. 1962. California  
Research Corp., Richmond, Calif. 15 Feb. 1963. 76p.  
illus. Contract: DA-49-186-ORD-929. 14 refs.  
A63-3637

This is a progress report on research about the behavior of carbonaceous fuels at the anode of a fuel cell. Current-time curves at constant potential were shown to give very useful data with platinized porous electrodes. These data correlate well with potential-sweep data obtained with small platinum foil electrodes. It is proposed that these techniques be used to search for catalysts, fuels, and conditions which will allow efficient fuel cell operation with hydrocarbons. Olefins give higher oxidation currents than alkanes on platinum but only at potentials too close to the oxygen electrode potential for practical use; there is hope that the position of principal oxidation peaks can be shifted to more practical potentials. Relative performances of several platinized porous-carbon electrodes were determined with propane and with hydrogen. The best currents with propane were about 5 ma at 0.3 volt; with propylene 10 ma/cm<sup>2</sup> at 0.625 volt

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and 25 ma/cm<sup>2</sup> at 0.8 volt. Ethylene is more reactive than propylene. Solubilities of ethylene, the light hydrocarbon series from methane to butane, and carbon dioxide are being determined; the incomplete data in the literature are tabulated. The anodic oxidation of ethylene and methanol may yield higher current densities per unit concentration than ethylene, but at higher overpotentials the reverse is true. Further work using the chronopotentiometric method strengthens the initial hypothesis that one of the current-limiting processes on platinized-platinum anodes may be diffusion of ethylene to the anode surface. A study was made of the oxidation of methanol, formic acid, and ethylene at a rotating, smooth platinum disk electrode. Oxidation waves from current-voltage curves of methanol and formic acid decreased with increasing rotational velocity of the disk electrode. The oxidation waves for ethylene were essentially unaffected by stirring. From these results we can conclude that the rates of oxidation of these compounds are not diffusion limited. The effects with methanol and formic acid were in accord with a derived equation which assumed that intermediates are formed during oxidation. These intermediates can diffuse away from the electrode or react further at the electrode surface. The results with ethylene indicate that any intermediates formed react further before diffusion from the electrode can occur. The peak current decreases with time at open circuit between voltage sweeps, suggesting that ethylene reacts slowly at platinum electrodes on open circuit to form compounds difficult to oxidize electrochemically. Potential-sweep data for a newly designed electron paramagnetic resonance (EPR) electrode has been related to standard data. The anode potential was found to be a simple function of the voltage measured and controlled by the potentiostat. The anode still is unstable electrically and it is planned to design a new cell for maximum current stability. A program of screening electrocatalysts has commenced. Chronopotentiograms of a platinum black-graphite paste electrode is more active than a platinized-platinum foil electrode. Studies of chemisorption of the gases on an electrode are underway; thus far, results have been unsatisfactory.

#### References

1. Tarmy, B. L., "The Soluble Carbonaceous Fuel-Air Fuel Cell," ARPA Conference, Whiting, Indiana (February 1962).

2-413 LOW TEMPERATURE BA-2270/U-XLT-1 BATTERIES.  
J. W. Paulson. Interim Report no. 4, 15 Aug. 1961 -  
31 July 1962. Ray-O-Vac Co., Madison, Wisconsin, Div.,  
The Electric Storage Battery Co. 11p. Contract:  
DA-36-039-SC-78144. AD 287 865. A63-3051.

The purpose of this work was to construct 500 BA-2270/U batteries of the flat cell type for initial and delayed service testing. Of the 500 production run batteries, 400 employed the LiCl:CP-2 electrolyte: separator combina-

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tion and 100 used the LiBr:CP-2 combination. Twenty-four months delayed testing results are discussed in this report for the LiCl:CP-2 low temperature LeClanche system. Discharge tests were run at 70°F, -20°F, and -40°F, after 24 months storage at both 70°F and 35°F. Because of the high percentage of failures at both storage temperatures and the high variation of performance, no conclusions can be drawn on the effect of storage temperature on delayed performance. Examination of batteries showed that failures or low performance was mainly due to the following factors: preferential corrosion of the zinc anode around the solder joint which bonds the zinc paralleling strip to the zinc anode; electrolyte leakage through pinholes in the conductive film; leakage of electrolyte through defective heat seals, and corrosion of lead wire connections at the stack. Details on battery specifications and procedures will be presented in the final report.

2-414 MERCURY CELL BATTERY INVESTIGATION. J. M. Booe and R. E. Ralston. R. R. Mallory and Co., Inc., Indianapolis, Final Report, ASD-TDR-62-1112. Jan. 1963. 59p. illus. Contract: AF 33(657)-7706, Proj. 8173, Task 817304-14. A63-2496.

The rechargeable electrochemical system zinc/potassium hydroxide/mercuric oxide-silver has been investigated from the viewpoint of aerospace requirements. Two versions of an exploratory research cell, with accompanying pellet type reference electrode, were successfully used during positive and negative electrode charge-discharge experiments. Zinc anodes containing high percentages of mercury were discharged with efficiencies over 90% at rates up to 2000 ma/in<sup>2</sup> under uninhibited conditions. Reliable apparatus was developed to determine the gas volume generated during chemical reactivity rate studies between high mercury content anodes and electrolytes. The system of Zn-Hg-Ag was found to be quite compatible with electrolyte containing zincate. A cell cup retaining member for the high mercury-zinc alloy was fabricated and employed in completed cells. Discharge utilization obtained was comparable to that obtained in the research cell. Results obtained during electrolyte additive studies were not encouraging. A comprehensive study of separator materials was made. Electrical resistance, tensile strength, and metal ion content values were obtained on commercially available and specially prepared materials after various exposure periods. Positive electrode densification experienced during cycle testing appears to be related to cycle depth. The additives which were investigated did not minimize the situation when electrodes were deep cycled. The use of palladium in the positive electrode alloy improved charge efficiency. Automatic cycle testing equipment was used to accumulate data on the two hour simulated orbit cycle. Several preliminary test vehicle cells completed more than 1000 cycles. A ten cell series connected battery with controlled overall charging voltage, completed 300 cycles before the first failure occurred.

2-415      **NEW CATHODE-ANODE COUPLES USING NONAQUEOUS ELECTROLYTES.** J. E. Chilton and G. M. Cook.  
Period covered: Dec. 1961-Aug. 1962. Lockheed Missiles & Space Co., Sunnyvale, Calif., Final Report, ASD-TDR-62-837. Dec. 1962. 48p. illus. Contract: AF 33(616)-7957, Proj. 8173, Task 817304. 3 refs. A63-1857.

New cathode-anode couples using nonaqueous electrolytes are investigated as possible secondary batteries for use in orbiting satellites. These studies are directed toward the construction of an operating secondary system. A lithium anode is used with either a silver chloride or nickel chloride cathode in an electrolyte consisting of propylene carbonate, aluminum chloride, and lithium chloride. The electrolyte is studied in detail. The extent of the solubility of lithium chloride is found to increase with an increase in aluminum chloride concentration. Electrical conductivity measurements show a low activation energy for conduction. These experiments also allow the prediction of a mechanism for the ionic conductivity of the electrolyte. Migration experiments agree with the predicted mechanism. Electrode reactions are studied in detail. The propylene carbonate-aluminum chloride electrolyte is found to be stable, i. e., aluminum is not deposited during electrolysis and the solvent does not decompose at the normal operating voltage for the system. Many metals were anodically oxidized in this electrolyte and found to be somewhat soluble and therefore unsuitable for use. Lithium metal is electrodeposited at 100-percent efficiency at current densities up to at least 80 ma/cm<sup>2</sup>. Nickel chloride is produced at 100-percent efficiency only at very low current densities, whereas silver chloride is produced at 100-percent efficiency at current densities up to at least 72 ma/cm<sup>2</sup>. Polarization experiments indicate that mass transport may be the limiting factor for the silver chloride cathode during discharge. Many materials and methods were used in testing anodes, cathodes, separator materials, and cell case and cell case construction. Various combinations were tested by actual cell cycling. Automatic cycling equipment was designed and assembled and is described. Data is collected on punched cards to provide easy access. Test cells have operated for over 200 cycles at overall coulombic efficiencies approaching 100 percent. Electrode spacing experiments indicate that cells are limited primarily by resistance. Over 80 percent of this resistance arises from the glass fiber filter paper presently used for ease in handling. Because of the inactivity of aluminum chloride in the electrolyte cell, voltage rises rapidly once lithium chloride is depleted. Thus a simple voltage cutoff device is the only safety device required for cycling operations. A cell was successfully cycled at -28°C. (Author)

- 2-416 RESEARCH RELATING TO FUEL CELLS HYDROGEN  
DIFFUSION ELECTRODE. A. C. Makrides. Quarterly  
Progress Report no. 1, covering period through 31 Dec.  
1962. Tyco Labs., Inc., Bear-Hill, Waltham, Mass.  
Jan. 1963. 25p. Contract: DA-49-186-ORD-982.  
50 refs. A63-2570.

Rates of hydrogen transport through Pd and Pd-Ag membranes were measured as a function of hydrogen pressure, temperature, and surface preparation. Permeation rates were determined with one side of the membrane exposed either to vacuum or to an electrolyte. In the latter case, the permeation rate through the membrane was obtained from the rate of hydrogen oxidation at the electrolyte interface at a series of controlled potentials. The room temperature permeation rate of hydrogen through Pd-Ag alloys depends critically on the activity of the membrane surface. The permeation rate for smooth Pd membranes is of the order of  $10^{-9}$  cc (NTP)/cm<sup>2</sup>/sec. It increases by a factor of  $10^5$  when a coat of Pd black is deposited on the surface. The transport rate through a palladized, 0.04 mm thick, 20% Ag-Pd membrane is  $2 \times 10^{-3}$  cc (NTP)/cm<sup>2</sup>/sec at 30°C. The equivalent current density for hydrogen oxidation in an electrolytic cell in which hydrogen is supplied by solid state diffusion through a Pd-Ag electrode is 20 ma/cm<sup>2</sup>. An analysis of potentiostatic transients shows that the permeation rate through palladized membranes is still limited by the kinetics of adsorption and solution at the gas/membrane interface. This conclusion is confirmed by a theoretical calculation of the solid state diffusion rate expected in the absence of slow surface processes. (Author)

- 2-417 SILVER-CADMIUM BATTERY DEVELOPMENT PROGRAM.  
John W. Rhyne, Jr. Quarterly Technical Progress Report,  
for Fifth Quarter, ending 20 Nov. 1962. Telecomputing  
Corp., Denver. 17 Dec. 1962. 42p. illus. Contract:  
NAS5-1431. A63-375.

The final cell case material has been selected. In the last report, attention was being given to the evaluation of four systems: Styrene; Styrene coated with Saran F-120; Saran F-120; Epoxy-polyamide. Of these, Styrene and epoxy-polyamide were felt to be applicable, since Saran had previously been found to be electrochemically incompatible. Subsequently, epoxy-polyamide was found to precipitate free silver from an alkaline solution of silver oxide at 120°F. The reaction was not noted at room temperature. The material chosen was Tyril 767, a styrene-acrylonitrile copolymer,\* which was found to be electrochemically inert under the proposed operating conditions. The final cell case design is an injection molded piece with provision for plate lead wires and a filling port and plug. Cases, lids, spacers and plugs have been molded for production of the batteries called for in the program.

2-417 (Continued)

Various cases were submitted to air pressure tests, low temperature tests, KOH-permeability tests, vibration and leak rate determinations and burst tests. Several types of cell constructions were evaluated for the purpose of selecting a prototype design.

- 2-418 SILVER-CADMIUM BATTERY DEVELOPMENT PROGRAM.  
James M. Rice. Quarterly Technical Progress Report for  
6th Quarter, ending 20 Feb. 1963. Power Sources Div.,  
Telecomputing Corp., Denver. 18 Mar. 1963. 8p.  
Contract: NAS5-1431. A63-3966.

During this report period, Phase I work has been completed with the finalized design of the filament wound battery case. This consists of an acrylic-glass cloth lay-up applied to the styrene mandrel as a substrate for the filament winding of glass roving/epoxy-polyamide case. Manufacture of the requisite cells for the completion of Phase III has been accomplished, and these cells are currently being formed and matched into battery groups. Batteries 1, 2 and 3 have been placed on test.

- 2-419 SOLUBLE CARBONACEOUS FUEL-AIR FUEL CELL.  
Barry L. Tarmy, Eugene L. Holt, Duane G. Levine,  
Andreas W. Moerikofer, Joseph A. Shropshire, and  
Charles H. Worsham. Rept. no. 2, 1 Jan.-31 Dec. 1962.  
Esso Research and Engineering Co., Linden, N. J.,  
Final Report, RL-60M-62. 107p. illus. Contract:  
DA 36-039-SC-89156, Task 760200471, ARPA order no.  
247-62. 8 refs. A63-2832.

Work on the performance and compatibility of the major components of a soluble carbonaceous fuel/air fuel cell has resulted in both improved performance and a greater understanding of the processes involved. Methanol has been selected as the prime fuel. Its advantages are high reactivity, low polarization in long term operation, and lowest cost. Its two inherent disadvantages, a high vapor pressure and poisoning of the air electrode, have been circumvented by reducing the concentration at the cathode to tolerable limits. Further reduction has been achieved by reacting most of the fuel within the anode structure. Severe polarization occurring at the methanol electrode was the greatest source of voltage loss; efforts to find a catalyst more active than platinum and yet stable in  $H_2SO_4$  have uncovered a number of materials. Included are Pt-Mo, Pt-Fe, and a proprietary catalyst. These have activities up to 150 mv better than platinum. A life study of about 800 hours on a platinum electrode showed that efficiency is essentially unimpaired if the cell is occasionally open circuited for several seconds and the methanol concentration carefully controlled. The air electrode developed uses a redox system based on the electrolytic reduction of a small quantity of nitric acid in the electrolyte.

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Air is used indirectly, in the chemical regeneration of the nitric acid. Its advantages are low polarization and long life. The major problems have been obtaining efficient nitric acid regeneration and determining the compatibility of the nitric acid redox system with the fuel electrode. Regeneration efficiencies with air of about 30 coulombs/coulomb equivalent to nitric acid consumed were achieved in an operating cell. The tolerance levels for nitric acid and methanol were determined and shown to allow efficient cell operation. A number of complete cells were built and tested from 3 to 35 hours; good agreement with half cell studies was obtained. There have been considerable improvements in performance and reliability. Current densities as high as 95 ma/cm<sup>2</sup> have been obtained; furthermore, power outputs of 32 mw/cm<sup>2</sup>, ex IR losses and 15 mw/cm<sup>2</sup> at the terminals have been obtained with the expectation of higher performance in the future. Further work is recommended on improvement of catalysts, where the possibilities of the largest increases in cell efficiency remain. Major efforts on the redox air electrode should be on improving catalyst efficiency and reducing the volume required for nitric acid regeneration. Problems in long-term cell operation include feed intake and product removal, and developing methods of startup and shutdown.

2-420 A THIN-PLATE BATTERY. J. F. Ambrose, J. Smit, and G. R. Crocker. Supplement to Seventh Quarterly Report on Molecular Circuit Development, 15 Nov. 1961-15 Feb. 1962. Melpar, Inc., Sub. of Westinghouse Air Brake Co., Falls Church, Virginia. 29p. Contract: NOw 60-0362-C. AD 272 275. A63-369.

This supplement gives the results of demonstrating the feasibility of miniaturizing the NOL Liquid Ammonia Activated Cell to meet Bur-Weapons requirements. The effect of varying such cell parameters as cell thickness, electrolyte concentration, activation pressure, and weight of cathode material is studied. The criteria used to evaluate cell performance are the peak voltage value, the time required for the voltage to drop to 80% and 50% of its peak value, the energy produced during these two time intervals, the charge transported during the 50% interval, and the total charge transported to cut-off. Cut-off time is not fixed, but usually occurs after the voltage has dropped to a little below 50% of its peak value. These criteria have been chosen with ultimate power source design requirements in view, and are essentially arbitrary because they do not represent points of any particular mathematical significance on the current-time discharge curves.



CHEMICAL SOURCES OF ENERGY - CITATIONS ONLY

THE AgO-Ag<sub>2</sub>O ELECTRODE IN ALKALINE SOLUTION.

Thedford P. Dirkac. Calvin College, Grand Rapids, Mich., Rept. no. 12.  
1 Mar. 1961. 11p. Contract: NOnr 1682(01), Task NR 359-364. 17 refs.  
A63-1540.

ALKALINE BATTERY EVALUATION. W. W. Clark, W. G. Ingling,  
I. F. Luke, and R. Leaf. (This report covers work conducted from  
beginning of Contract AF 33(657)-8350 to 30 Sept. 1962). Cook Electric Co.,  
Inland Testing Labs., Dayton, Final Report, ASD-TDR-62-893, Part II.  
(This report supersedes ASD TR 61-236, ASD-TDR-62-68, and ASD-TDR-  
62-553). Oct. 1962. 43p. illus. Contract: AF 33(616)-8450.  
A62-12426, pt. 2.

See abstract for Part I.

ELECTROCHEMICAL ENERGY CONVERSION SYSTEMS RESEARCH.

John O. Smith, Ralph G. Gentile, Frank B. Leitz, and Dominick A. Sama.  
Period covered: 29 Sept. 1960-28 Sept. 1961. Monsanto Research Corp.,  
Boston Labs., Everett, Mass., Final Report, MRC Bos Fin 30.  
20 Nov. 1961. 70p. illus. Contract: DA 19-120-QM-1698(01 5017),  
Proj. 7x80-01-New. A63-2501.

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Development Corp., Dallas, Penna., No rept. no. 34p. illus. Contract:  
DA-44-009-ENG-4864. A63-2725.

HIGH VOLTAGE, GAS ACTIVATED BATTERIES. William H. Deierhoi, Jr.  
Final Report, 9 Nov. 1959-31 Mar. 1961. Union Carbide Consumer Products  
Co., Cleveland. 30 June 1961. 48p. illus. Contract: DA-36-039-SC-74856.  
AD 275 792. A63-3340.

LOW TEMPERATURE BA-2270/U-XLT-1 BATTERIES. J. W. Paulson.  
Interim Report no. 3, 15 Feb.-15 Aug. 1961. Ray-O-Vac Co. Div., The  
Electric Storage Battery Co., Madison, Wisconsin. 11p. Contract:  
DA-36-039-SC-78144. AD 266 400. A63-3310.

ORGANIC DEPOLARIZED PRIMARY BATTERIES. G. S. Lozier,  
J. B. Eisen, and R. J. Ryan. Third Quarterly Progress Report, 15 Dec.  
1961-15 Mar. 1962. Radio Corp. of America, Sommerville, N. J.,  
Semiconductor and Materials Div. 21p. illus. Contract:  
DA-36-039-SC-87243, Proj. 3A99-09-002. AD 281 920. A63-3309.

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PRODUCTION OF A SERIES OF NICKEL-CADMIUM BATTERY TESTERS. A. W. Speyers, F. J. Keim, and R. B. Naugle. Final Engineering Report, 18 Aug. 1955-30 Nov. 1958. Vitro Labs., West Orange, N. J., Rept. no. KLX-10137. 59p. illus. Contract: DA-36-039-SC-64703, Proj. 20555. 2 refs. AD 229 195. A63-484.

RESEARCH RELATING TO FUEL CELLS. A. K. M. Shamsul Huq. Quarterly Report no. 1, 20 Sept.-31 Dec. 1961. TYCO, Inc., Bear Hill, Waltham, Mass., Materials Research Lab. 5 Jan. 1962. 4p. illus. Contract: DA-49-186-ORD-982. AD 270 302. A62-5247.

A STUDY OF THE ADSORPTION MECHANISMS ON OXYGEN ELECTRODES. Y. L. Sandler. First Semiannual Report, 15 July 1961-15 Jan. 1962. Westinghouse Electric Corp., Pittsburgh. 19 Jan. 1962. 44p. illus. Contract: DA-36-039-SC-89138, ARPA order no. 226-61. 17 refs. AD 274 764. A63-3234.

SYSTEM ANALYSIS OF A REFENERATIVE HYDROGEN-OXYGEN FUEL CELL POWERPLANT. Albert C. Ching and Frederick Cohen. Period covered: 1 Sept.-31 Dec. 1961. Pratt and Whitney Aircraft Div., United Aircraft Corp., East Hartford, Conn., Final Report, PWA-2020. 31 Dec. 1961. 75p. illus. Contract: DA-36-039-SC-88903, Proj. 1(303145), Task 60813. AD 283 789. A63-3222.

A THIN-PLATE BATTERY. J. F. Ambrose and J. Smit. Supplement to Eighth Quarterly Report on Molecular Circuit Development, 15 Feb.-15 May 1962. Melpar, Inc., Sub. of Westinghouse Air Brake Co., Falls Church, Va. 32p. illus. Contract: NOw 60-0362-c. AD 275 284. A63-3220.

## SECTION C - MAGNETOHYDRODYNAMIC SYSTEMS

- 2-421 MAGNETOHYDRODYNAMICS AND ENERGY CONVERSION.  
 Technical Status Report no. 9, for period ending 30 Nov. 1962.  
 (This report was included as a section of Quarterly Progress  
 Report no. 68, 15 Jan. 1963, of the Research Lab. of  
 Electronics). Massachusetts Inst. of Tech., Cambridge,  
Research Lab. of Electronics. 15 Dec. 1962. p. 101-19.  
 Contract: AF 33(616)-7624. 17 refs. No accession no.

The first portion of this report contains statements of research objectives covering the following subjects: plasma magnetohydrodynamics, energy conversion, alkali-metal magnetohydrodynamic generators, and magneto-fluid dynamics. The second portion of this report contains descriptions of work done on the experimental measurement of the thermal conductivity of cesium vapor, a theoretical analysis of a work function of a conductor, and an analysis of the power flow in the magnetohydrodynamic induction machine. An experimental measurement of the thermal conductivity of cesium vapor was made by a variation of the hot-wire cell method. This method provided for the unfavorable ratio of heat fluxes caused by the difference in heat transfer from thermal radiation as opposed to that resulting from thermal conduction. Two experimental measurements were made (at 600 and 603°K) resulting in values of 0.002946 Btu/hr ft<sup>2</sup>F and 0.003046 Btu/hr ft<sup>2</sup>F respectively.

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2. L. O. Hoppie, The Electrohydrodynamic Traveling-Wave Amplifier: An Application of Low Conductivity Plasma, S.B. Thesis, Department of Electrical Engineering, M.I.T., 1962.
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SECTION D - MECHANICAL DEVICES

- 2-422      **APPLIED RESEARCH ON A HERMETICALLY-SEALED DRIVE COUPLING FOR SPACE POWER TRANSMISSION.**  
Third Quarterly Progress Report, 1 Nov. 1962-31 Jan. 1963.  
TAPCO Div., Thompson Ramo Wooldridge Inc., Cleveland,  
Rept. no. ER-5224. Feb. 1963. 28p. illus. Contract:  
AF 33(657)-8486. 2 refs. A63-2285.

The design requirements provide for power transmission through a continuous boundary with a device having a 90% over-all efficiency and 10,000 hours of maintenance free design life. Operating conditions will be 20 to 40 psi pressure differential, 1000°F potassium vapor on one side of the boundary, and  $10^{-5}$  mm Hg. vacuum on the opposite side. The following has been accomplished during the past three months of the program: (1) The detailed design of the electromagnetic coupling has been completed and the fabrication of all parts has been started; (2) The design of the high temperature potassium vapor and vacuum environment test rig has been completed, the fabrication of all parts has been started, and the installation of the supporting equipment is in process; and (3) The high frequency evaluation test of various bellows configurations for the deformable membrane coupling has been started and is 25% complete.

- 2-423      **CONSTANT OBLIQUE FIELD, ELECTROSTATIC GENERATOR.**  
Hermann Anton, Dominique Gignoux, and John J. Shea.  
Cosmic, Inc., Washington, D. C., Rept. no. 41;  
ASD-TDR-63-87. Feb. 1963. 53p. illus. Contract:  
AF 33(657)-7769, Proj. 8128, Task 812808. 9 refs.  
A63-2955.

The principle of operation of the constant oblique field, electrostatic generator is described and the increase in power obtained from a generator featuring this field arrangement is predicted from theoretical investigations. A generator has been built and tested in air and in a vacuum environment of  $2 \times 10^{-7}$  to  $7 \times 10^{-7}$  mmHg. The results of the tests in air have met those anticipated. A five-inch diameter rotor has produced a power of 12.5 watts at 15,000 rpm. The vacuum tests have yielded values somewhat greater than those obtained in air, whereas data from previous experimenters show that an increase in power by a factor of 50-100 should be expected. (Author)

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2-424 FEASIBILITY AND DESIGN STUDY FOR ELECTROSTATIC GENERATORS. A. S. Denholm, F. J. McCoy, C. N. Coenraads, and J. E. Lavelle. Period covered: 1 Nov. 196--31 Nov. 1962. Ion Physics Corp., Burlington, Mass., WADD-TR-61-105, Vol. II. Feb. 1963. 112p. illus. Contract: AF 33(616)-7230, Proj. 8128, Task 812808. 16 refs. A63-3679, vol. 2.

Results of studies of vacuum breakdown pertaining to electrostatic generators for operation in vacuum are given. Insulation strength obtained has increased significantly. The influence of discharge energy and pulsing on electrode conditioning is discussed. High speed seal development has been successful and vacuum was maintained in the  $10^{-6}$  torr range while spinning at 10,000 rpm. The feasibility of electronic commutation methods is shown. Electrostatic generator progress is discussed and test data are given. The maximum output power to date was 200 watts. (Author)

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2-425 FEASIBILITY AND DESIGN STUDY FOR THE 1 KW/5 KW ELECTROSTATIC GENERATORS. F. J. McCoy, J. Lavelle, and C. N. Coenraads. Quarterly Technical Progress Report no. 3. Ion Physics Corp., Burlington, Mass. 31 Jan. 1963. 27p. illus. Contract: AF 33(616)-7230, Proj. 0(3-3145), Task 61081. 2 refs. A63-3254.

Progress was made in the study of voltage insulation in vacuum. Several tests were run to determine the effects of area of electrode, increased resistance, increased pressure, and increased energy. There seemed to be no way in which to obtain high fields at a low current level by simply varying pressure or energy. It was decided to attempt coating the cathode. A high temperature epoxy (Eccocoat G-26) with a surface resistivity of  $10^{15}$  ohm-cm and a volume resistivity of  $10^{16}$  ohm-cm was used. Several methods of obtaining dust and bubble free coatings were tried. Preliminary tests with imperfect coatings proved promising. Three aluminum electrodes were anodized by treatment with chromic acid which gave a coating of  $\text{CrO}_2 + \text{Al}_2\text{O}_3$ . Tests run with these cathodes and anodes of Ti-7Al-4Mo alloy showed an insulation strength of 65 kv and a maximum voltage of 70 kv; however, the first spark occurred at 20 kv as opposed to 40 kv for cathodes anodized by the Martin Hardcoat method. Further testing of electrodes that had been subjected to the Multicleaning process proved that multicleaning is more effective as an insulating method than electrolyzing. The maximum power generated to date with the electrostatic generator was limited to 200 watts because of vibration, tolerance and contamination problems. The generator is now in a stage of consolidation and many problems which showed up in the previous months have been analyzed and solved or reduced. Contamination of the vacuum system with oil vapor from the high speed vacuum seal will, however, remain a problem. The machine is presently being assembled for the next series of tests.

#### References

1. "Feasibility and Design Study for the 1 KW/5KW Electrostatic Generators," AF33(616)-7230, Quarterly Technical Progress Report No. 2, 31 October 1962, Ion Physics Corporation, Burlington, Massachusetts.

2-424 (Continued)

3. Young, W.C., Clauss, F.J., Drake, S.P., "Lubrication of Ball Bearings for Space Applications," Lockheed Missiles and Space Co., Sunnyvale, California.
4. Sentyurikhina, L.N., Malyshev, B.N. et al, "A High Vacuum, High Temperature, Solid Lubricant", FTD-TT-61-58 AFSC, Wright-Patterson Air Force Base, Ohio.
5. Evans, H.E., and Flatley, T.W., "Bearings for Vacuum Operation Retainer Material and Design", NASA TN-D-1339, Goddard Space Flight Center, Greenbelt, Maryland:

2-425 FEASIBILITY AND DESIGN STUDY FOR THE 1 KW/5 KW ELECTROSTATIC GENERATORS. F. J. McCoy, J. Lavelle, and C. N. Coenraads. Quarterly Technical Progress Report no. 3. Ion Physics Corp., Burlington, Mass. 31 Jan. 1963. 27p. illus. Contract: AF 33(616)-7230, Proj. 0(3-3145), Task 61081. 2 refs. A63-3254.

Progress was made in the study of voltage insulation in vacuum. Several tests were run to determine the effects of area of electrode, increased resistance, increased pressure, and increased energy. There seemed to be no way in which to obtain high fields at a low current level by simply varying pressure or energy. It was decided to attempt coating the cathode. A high temperature epoxy (Eccocoat G-26) with a surface resistivity of  $10^{15}$  ohm-cm and a volume resistivity of  $10^{16}$  ohm-cm was used. Several methods of obtaining dust and bubble free coatings were tried. Preliminary tests with imperfect coatings proved promising. Three aluminum electrodes were anodized by treatment with chromic acid which gave a coating of  $\text{CrO}_2 + \text{Al}_2\text{O}_3$ . Tests run with these cathodes and anodes of Ti-7Al-4Mo alloy showed an insulation strength of 65 kv and a maximum voltage of 70 kv; however, the first spark occurred at 20 kv as opposed to 40 kv for cathodes anodized by the Martin Hardcoat method. Further testing of electrodes that had been subjected to the Multicleaning process proved that multicleaning is more effective as an insulating method than electrolyzing. The maximum power generated to date with the electrostatic generator was limited to 200 watts because of vibration, tolerance and contamination problems. The generator is now in a stage of consolidation and many problems which showed up in the previous months have been analyzed and solved or reduced. Contamination of the vacuum system with oil vapor from the high speed vacuum seal will, however, remain a problem. The machine is presently being assembled for the next series of tests.

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1. "Feasibility and Design Study for the 1 KW/5KW Electrostatic Generators," AF33(616)-7230, Quarterly Technical Progress Report No. 2, 31 October 1962, Ion Physics Corporation, Burlington, Massachusetts.

- 2-426 INVESTIGATION OF TECHNIQUES FOR 1000°F  
HYDRAULIC SYSTEMS. Part II--Nuclear Environment.  
Period covered: Feb. 1961-Nov. 1962. Republic Aviation  
Corp., Farmingdale, Long Island, N. Y., Final Report,  
ASD-TDR-62-674, Part II. 1 Mar. 1963. 56p. illus.  
Contract: AF 33(616)-7454, Proj. 8128, Task 812807.  
A62-9108, pt. 2.

This report covers the investigation, fabrication, and evaluation of a hydraulic sub-system and its components when significant portions of the system operate at a fluid temperature of 1000°F under nuclear environment. The effects of radiation, temperature, and a combination of both in the mixed polyphenyl ether fluid used in the system have been determined. Testing and evaluation of the system component under combined high temperature and nuclear environment are included. (Author)

- 2-427 PIEZOELECTRIC CONVERTER INVESTIGATION.  
Anthony Antonuzzi. Fourth Quarterly Report, 1 Dec. -  
28 Feb. 1963. U. S. Sonics Corp., Cambridge. 11p.  
Contract: AF 33(657)-8282. 3 refs. A63-3231.

The purpose of the study is the development of piezoelectric conversion materials. Output power vs. frequency at constant sound pressure level is presented for edge supported bilaminar transducers. Three ceramic materials of similar dimensions were tested, with each element terminating in a fixed resistive load matched at resonant conditions. Three elements were also tested under random noise conditions in a jet engine test cell using a J-57 jet engine as a noise source. A discussion of the theoretical stress limits for the edge supported piezoelectric disc is also presented. The conversion efficiency for the simple supported edge piezoelectric discs tested is in the range of 7-9% when excited by a single frequency acoustic field corresponding to the resonance frequency of the disc. The response drops sharply at frequencies removed from resonance. Thus, in a wide band sound level, efficiency drops sharply if it is based on the overall energy available. The power and efficiency data recorded have been based on acoustic energy impinging directly on the surface of the disc with no attempt to improve the impedance match between air and the mechanical system. Work has now begun to improve this coupling.



2-428      **STUDY, DESIGN, AND TEST OF EXPERIMENTAL LIQUID HYDROGEN PUMP FOR USE IN FLIGHT VEHICLE SYSTEMS.**  
F. R. Ostiek. Period covered: 15 Feb. -15 Oct. 1962.  
Rocketdyne, Div. of North American Aviation, Inc.,  
Canoga Park, Calif., Final Report, R-3892; ASD-TDR-63-114.  
Feb. 1963. 196p. illus. Contract: AF 33(657)-8062,  
Proj. 3145, Task 30328. 24 refs. A63-2730.

This technical report describes the first phase of a research program on low flowrate, high pressure two-phase hydrogen pumps for potential space applications in auxiliary power systems and low-thrust chemical rocket engines. This program is directed toward the solution to the following main problem areas: (1) Pumping a variable quality fluid. Determine if it is feasible for a pump to deliver 1200 psi hydrogen when the inlet conditions vary from all liquid to all vapor; (2) Thermal protection of the pump. Define a means of isolating the pump from an environment of up to 300°F; and (3) Materials. Establish the compatibility of materials at liquid hydrogen temperature when they are in sliding contact, as well as evaluate materials for sealing applications of liquid hydrogen. The general requirements and specifications governing the design and analysis of the liquid-hydrogen micropump are: (1) Flowrate: 2 to 12 lb/hr; (2) Inlet pressure: 43 psia, saturated liquid hydrogen; (3) Discharge pressure: 1200 + 50 psia at all flowrates; (4) Inlet fluid quality: From all-liquid to all-saturated vapor (a design objective, not a requirement); (5) Lubrication: No outside means of lubrication; (6) Leakage: Zero external leakage is a design objective; (7) Gravity field: The pump shall be capable of continuous operation in any position in a gravity field of zero to several g; and (8) Operating environment: The experimental pump shall be capable of continuous operation in a 100°F and 15 psia environment. There shall be no cooling fluid other than the hydrogen pumped. Ultimately the pump should be capable of operating in a 300°F and 5 to 10 psia environment. In performing this program, a general analysis of the pumping requirements was made to outline the areas which presented the most serious problems and to establish the ground rules for the analysis of pumps meeting these pumping requirements. The analysis technique, for evaluating various types of pumps, is based on similarity considerations and is described in this report. The first order analysis of all typical pumps was performed. The results of this comprehensive survey are presented in the form of a comparative set of curves which indicate the pumping regimes for which each type of pump is suitable. An examination of these data indicates that only three types of pumps are acceptable candidates for this application: (1) The liquid ring pump; (2) The Tesla pump; and (3) The piston pump. A more detailed analysis was performed on the three pumps to determine whether any real advantages could be attributed to one or more of the pumps. Although both the liquid ring and Tesla pumps have considerable merit, neither is competitive to the piston

( ) 2-428 (Continued)

pump at the low flowrates specified. In fact, even with 10 times the design flowrate of 12 lb/hr the piston pump is superior. The piston pump was selected, therefore, as the most suitable pump for this application. A detailed analysis of the piston pump has been performed yielding a technique for determining the optimum pump configuration. By applying this technique to the specified requirements, the optimum design configuration was determined and the expected pump characteristics ascertained. Simultaneous with the analytical investigations, extensive mechanical design studies were conducted which led to finalization of an experimental pump design. A test fixture to evaluate key materials problems was designed and fabricated. Test runs with liquid hydrogen under simulated pumping conditions yielded valuable data regarding materials compatibility and allowable clearances between piston and cylinder. This test fixture used a 1-inch diameter piston with a 1/2-inch stroke. Diametral clearances of  $50 \times 10^{-6}$  inches and  $80 \times 10^{-6}$  inches were used in these tests. Better operation resulted with the  $80 \times 10^{-6}$  inch clearance. A total of 75 hours of intermittent operation was accumulated with this clearance. The materials for this test were an electrolyzed stainless-steel cylinder and a chrome plated stainless-steel piston. The results from these tests provided adequate data to permit a realistic design of the experimental pump. During the past years, the Liquid Rocket Engineering Division of Rocketdyne has performed extensive bearing and seal programs using liquid hydrogen as well as other cryogenic fluids. Sufficient test data are available to permit confidence in the design of the micropump. A detailed discussion of the bearing and seal test data is given in an appendix.

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SECTION E - NUCLEAR SOURCES OF ENERGY

- 2-429 BURNUP ENHANCEMENT FOR REENTERING NAP SYSTEMS.  
Study 2. Ninth Monthly Progress Letter Report, 28 Feb. -  
31 Mar. 1963. Battelle Memorial Inst., Columbus, Letter  
dated 12 Apr. 1963. 3p. Contract: AF 29(601)-4939,  
Proj. 1831, Task 183101. No accession no.

The damage to the rocket test facility caused by explosions during an earlier burnup test with hydrided U-Zr alloy has been repaired. The test facility has been instrumented so that more reliable information on ignition at low flow may be recorded. The recleaning of the particle collection system has begun in preparation for ablation testing. Base-line purity of the coolant and collection water is being established. It is expected that most of the ablation testing will be completed during the next reporting period.

- 2-430 FLIGHT TEST CRITERIA FOR REENTERING NAP SYSTEM.  
North American Aviation, Inc., Space and Information  
Systems Div., Downey, Calif., AFSWC-TDR-62-83.  
Nov. 1962. 143p. illus. Contract: AF 29(601)-5104,  
Proj. 1831, Task 183103. 12 refs. A63-1569.

This interim report covers Phase A of the Flight Test Criteria Study which will determine criteria that can be used as guidelines in setting up a flight test program or in judging one that has been proposed. This study is intended to be universal in application to NAP reentry phenomena. The SNAP 10A was designated to provide a representative system for study. The various parameters considered and topics discussed in this report include orbital decay and thermodynamic data, scaling, instrumentation, launch vehicles and sites, and reliability. The results of the analysis of flight test criteria have indicated the following conclusions: The total heat input into the fuel element must duplicate the actual case, and the peak heat flux must be at least as high as that occurring during orbital decay. Combinations of reentry velocity and reentry flight-path angle have been determined to duplicate total heat input of an orbital decay. It will be necessary to achieve supercircular velocities (above 24,000 feet per second) for negative reentry angles. Higher velocities are required for larger negative reentry angles. A 300,000 foot reentry altitude can be used. Exposure above 300,000 feet is not necessary since the total heat input is less than 10 percent greater for exposure at 400,000 feet than for exposure at 300,000 feet. If exposed at higher altitudes, reentering bodies that have initial temperatures of more than 1000F may cool before reaching 300,000 feet. A full-scale fuel element should be used as a test specimen. The total heat required for burnup is proportional to rod diameter so that fuel elements of less than full scale will not demonstrate burnup of the actual fuel element. Specimens of larger diameter require more heat for burnup which may not be available. Any scaled fuel element specimen (larger or smaller) will present a different condition for internal heat transfer not

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representative of the actual fuel element. Instrumentation system requirements for NAP reentry tests are well within the present state-of-the-art, except for fuel-element ablation determination and particle-size measurements during free flight experiments. For these exceptions, available instrumentation is of very limited capability. Considerable research and development of equipment will be needed to meet these requirements adequately.

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2. Olsen, D. C., and H. G. Webb, Jr., "Stability and Control Manual, " North American Aviation Report SID 61-236, 28 August 1961.
3. Aeronautics and Astronautics Coordinating Board, Washington, "National Launch Vehicle Program Summary, " ASTIA AD322990, 14 February 1961.

2-431 GÉNÉRALITÉS SUR LES GÉNÉRATEURS DE PUISSANCE  
UTILISANT L'ÉNERGIE NUCLEAIRE (In French).  
(Review of Power Generators Using Nuclear Energy).  
T. Bret. Presented at Deuxième Symposium Spatial Européen,  
held 18-20 June 1962, Paris; sponsored by Société Française  
D'Astronautique and British Interplanetary Society. 11p.  
TL783.5 B844.

( ) This is a general review paper on the state-of-the-art. The sources cited are all American.

2-432 HIGH TEMPERATURE PROPERTY STUDY FOR  
REENTERING NAP SYSTEMS. Armour Research  
Foundation, Illinois Inst. of Tech., Chicago, Quarterly  
Report. Jan. 1963. 17p. illus. Proj. A 6003.  
A63-2117.

This is the fourth and final quarterly progress report on the study to determine the high temperature properties of hydrided zirconium-uranium fuel elements. The following properties of both unhydrided and hydrided zirconium-uranium alloy are being determined over the temperature range from 540 to 3260°R: (1) Thermal conductivity; (2) Specific heat; (3) Thermal expansion; (4) Total emissivity; (5) Heat of combustion; (6) Heat of fusion; (7) Tensile strength; (8) Rate of hydrogen diffusion; and (9) Rate of oxide formation. During the past quarter, determination of thermal conductivity, heat of fusion, total normal emissivity, rate of hydrogen loss, rate of oxide formation and loss of fuel element integrity under high heat flux were completed. Data on tensile strength are given, however, it is somewhat limited due to extreme difficulty in machining tensile test specimens from hydrided zirconium-uranium alloy. (Author)

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- 2-433      A NUCLEAR-PHOTON ENERGY CONVERSION STUDY.  
Quarterly Technical Report no. 3, 1 Oct. 1962-  
31 Dec. 1962. Armour Research Foundation, Illinois Inst.  
of Tech., Chicago, Rept. no. 1214-TR 3. 15 Jan. 1963.  
29p. illus. Contract: AF 33(657)-8527, Proj. 8173,  
Task 817301-17. 3 refs. A63-1603.

The temperature dependence and phosphor thickness dependence on the luminescence output was studied for several phosphors which appear promising for use in a nuclear-photon energy conversion system. In this system, beta particles from a radioisotope source are absorbed by the phosphor which emits a multiplicity of low energy photons. These photons are then converted to electrical energy by a photo-voltaic device. The most promising phosphor to date, a ZnCdS:Cu, had about a 15 percent decrease in luminescence intensity as the temperature was increased from room temperature to 120°C; and was found to be relatively transparent to its own light with an optimum thickness for Sr<sup>90</sup> beta excitation of 160 mg/cm<sup>2</sup>. Strontium-90 beta particle radiation damage studies on this phosphor indicate an onset of damage at a total radiation dose of 10<sup>8</sup> ergs/cm<sup>2</sup>. These data, in conjunction with the previously reported data on silicon cells, indicate that Sr<sup>90</sup> can not be used and that the maximum operating temperature is about 120°C. Calculations were made on the temperature restrictions on the double-conversion power source geometry. These calculations indicate that, with a maximum temperature of 120°C allowed in the device, a maximum power input density of 200 mw/cm<sup>2</sup> is permitted. Experiments are in progress on the source-phosphor geometry of an intimate powder mix of promethium-147 and ZnCdS:Cu. Also, experiments are being conducted on the fabrication of a single crystal phosphor - photovoltaic device. (Author)

- 2-434      A NUCLEAR-PHOTON ENERGY CONVERSION STUDY.  
H. V. Watts, M. D. Oestreich, and R. J. Robinson.  
Period covered: Apr. 1962-Feb. 1963. Armour Research  
Foundation, Illinois Inst. of Tech., Chicago, Final Report,  
ASD-TDR-63-244. Mar. 1963. 61p. illus. Contract:  
AF 33(657)-8527, Proj. 8173, Task 817301-17. 33 refs.  
A63-4527.

A double energy conversion technique was studied for aerospace use as a radioisotope powered 10 watt electrical output power source. In this technique, beta particles from a radioisotope are absorbed by a luminescent material which emits a multiplicity of low energy photons. These photons are then converted to electrical energy by a photovoltaic device. The three components (radioisotope, phosphor, and photovoltaic cell) are discussed individually and then in combination in various geometries of source-phosphor and phosphor-photovoltaic converter. Nuclear radiation

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effects on the phosphor and photovoltaic materials restrict the choice of the radioisotope to a low energy beta emitter; and temperature effects limit the number of "unit power cells" which may be stacked in one bundle. These effects are more pronounced in silicon photovoltaic converters than in ZnCdS: Cu type phosphors. A ten watt output power source fabricated with currently available materials (Pm-147, ZnCdS: Cu, and silicon photovoltaic cells) would have an overall energy conversion efficiency of about 0.2 percent and a power per weight ratio of 4 mw/lb. It is estimated that the power per weight could be increased by a factor of ten to forty if certain "ideal" materials were available. These ideal materials include high purity Tl-204 of nearly theoretical maximum specific activity, large transparent luminescent crystals of CdS with an optical half value thickness  $\geq 1.0$  cm., and a CdS photovoltaic surface barrier combined with the luminescent crystal. The rapid decrease in photovoltage and energy conversion efficiency of silicon cells at low illumination intensities causes an appreciable loss in the overall efficiency of such power source. For aerospace use, a ten watt self-powered double energy conversion source of this type does not appear useable because of its low specific power and the complexity of fabrication.

2-435 RADIONUCLIDE POWER SOURCES. J. G. Morse.  
Presented by Deuxième Symposium Spatial Européen,  
held 18-20 June 1962, Paris. 8p. 6 refs. TL796 M885.

A description of isotopic flight vehicle power systems now in use is given. Substantially the same paper is published in Science, 139, 1175, (22 March 1963).

2-436 SPACECRAFT ELECTRIC GENERATING AND PROPULSION  
SYSTEM INTEGRATION. Third Quarterly Status Report,  
for month ending 31 Dec. 1962. General Electric Co.,  
Cincinnati. 36p. Contract: AF 33(657)-8488. 4 refs.  
A63-2266.

The primary objectives of this program are: (1) To develop, demonstrate, and provide a working manual and digital computer program for the system design analysis and optimization procedure known as LEADER, and (2) To apply this procedure to space power-propulsion systems employing the SPUR 350 KW and 1 MW nuclear space power plants. The initial phase of the contract effort has been devoted to the solution of two illustrative problems, (1) optimization of a nuclear space power plant-transmission line system, and (2) optimization of a space power plant condensing radiator panel, as a means for satisfying the first objective. The results obtained for the two illustrative problems contain (1) the values of each of the independent design parameters which minimize the over-all system weight

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within the boundaries and constraints specified, (2) the value of the minimum over-all system weight, (3) the boundaries or constraints which prevent further reduction in over-all system weight, and (4) the sensitivity of the over-all system weight to small changes in the optimum design parameters. The process of solving the two illustrative problems has served to clarify the capabilities of the two computer programs comprising LEADER and to identify the various procedural elements which must be performed in order to achieve effective utilization of the LEADER technique. These procedural elements are being described in a User's Manual in order to facilitate the application of LEADER to subsequent problems. During the subject reporting period, the first part of this User's Manual has been completed and is included as a supplement to this progress report.

2-437 SPUR POWER SYSTEM. F. B. Wallace. Quarterly Progress Report for period ending 30 Sept. 1962. AiResearch Mfg. Div., Garrett Corp., Phoenix,  
Rept. no. SY-5396-R2. 15 Oct. 1962. 189p. illus.  
Contract: AF 33(657)-8954, Proj. 3145, Task 314511. A62-11457.

The ultimate objective of the SPUR program is to develop a nuclear-dynamic space power system capable of supplying 300 kw or more of electrical power, with a design life of 10,000 hours. Work was carried out on seven tasks during this report period. In the field of bearing development primary effort during this period was directed toward: solution of problems in compatibility of potassium with the lubricant for the motor and main spindle bearings; development of satisfactory seals; and accomplishment of a general design review. No satisfactory lubricant has been found. Tests are projected for several low viscosity, narrow cut petroleum or mineral base fluids without additive packages. Initial problems with the dynamic face seal have been traced to extreme out-of-flatness condition on the rotor and steps have been taken to eliminate this problem. Work on turbine development included turbine test rig design, the turbine test facility, and turbine material erosion tests. The original SPUR turbine design was reevaluated. Complete development of the evaluation is presented. This includes a vector diagram study, estimate of wet turbine efficiency, a further discussion of problems related to the potassium lubricated bearings, and a preliminary critical speed analysis of the turbine test rig. Work on the turbine test facility continued. Design progress is reported along with a discussion of problem areas. Turbine material erosion tests during this period took the form of preliminary water tests and potassium test rig fabrication. During this report period three new tasks were added to the generator development program. The new tasks included generator rigid insulation, joining Hiperc 27 alloy

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to columbium and 50 kw liquid metal model generator development. The A-C generator design work progressed with approximately 100 generator design variations being calculated on the IBM 7090. Results of the following studies are reported in detail: parametric design study using 600°F and 800°F coolant; rotor stress analysis and cooling requirements; effect of stack lamination thickness; effect of pole face slots; effect of field coil relocation; stator heat transfer studies; and rotor stress and dynamics studies. Generator test rig design studies continued. An investigation of five variable speed drive types was conducted based on the input requirements to the generator and the nature and scope of the tests planned. Results of the survey are presented. Specifications for instrument components have been prepared and submitted to various suppliers. Preparation for supply of adequate power to the test rig has been made. Work moved forward on the stator ceramic seal. Testing of the full scale cylindrical ceramic tube for the liner is described. Exploration of the possibilities of using Battelle's new process for production of ceramic body densities closely approaching the theoretical maximum is being investigated. Work on joints between metal and ceramic components included letting of a contract for the development of the braze joining technique, and procurement and fabrication of joint testing equipment. Design, testing and materials studies continued on the electrical insulation task. Heat transfer development included single tube boiling potassium tests, air water separator tests, flow visualization studies, stainless steel heat transfer components studies, and stainless steel heat transfer loop studies. Work on controls development consisted of a steady state controls analysis and a start-up and load change analysis. Due to the failure of an argon seal while operating the reactor loop pump during the last period, efforts were made during this period to repair and modify the pump. After completion of the modifications, the loop was refilled with lithium and the pump was placed in operation; once again trouble was encountered due to leakage of molybdenum from the molybdenum coating on the bearing. Pratt and Whitney was visited to determine if the SNAP-50 reactor loop can be simulated and analyzed. Programming of the dynamic equations representing reactor loop normal operation was completed during the report period. Development of these equations is presented in detail. The objective of the properties of reactor clad and structural materials task is to obtain creep data on Cb+1 w/o Zr in contact with lithium in the temperature range corresponding to the SPUR reactor loop design conditions. Description of work done on this task is reported in detail.



2-438 SPUR POWER SYSTEM. F. B. Wallace. Quarterly Progress Report, for period ending 31 December 1962. AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5396-R3. 15 Jan. 1963. 183p. illus. Contract: AF 33(657)-8954; Proj. 3145, Task 314511. A63-1444.

The AiResearch Mfg. Div. of the Garrett Corp. is performing work on a Phase II contract for the SPUR nuclear reactor space power system. This is a continuation of earlier efforts by this firm. The Phase II contract calls for continued analytical and experimental studies in the areas of materials testing, bearing development, turbine development, liquid-metal-cooled generator development, heat-transfer loop design, and reactor controls development and reactor loop analysis. The rather scattered list of components involved in the contract is being developed or studied under a total of 32 tasks. This report narrates progress by AiResearch and by several subcontractors during the last quarter of 1962. Results reported for materials testing include creep-rupture of Mo-Ti alloys, fatigue testing of Mo-Ti and Cb-Zr alloys, creep rupture of SAE 4340 steel, and mass-transfer tests with liquid K -- all in connection with high-temperature liquid-metal environments. Columbium welding techniques are also being investigated. In bearing development, lubricants were evaluated for compatibility with K, and test design and development work for other tests continued. Turbine development results include extensive data from design studies on turbine blade shapes and more limited work on turbine material erosion tests. Generator design was completed through the layout drawing. The design parameters are listed and features of the design are discussed at length. In heat transfer development, component fabrication was completed and loop assembly work was started. Flow studies were pursued to develop methods and instruments for later heat transfer loop tests. Analysis of heat transfer loop component materials was completed, and layout design for a stainless steel heat transfer loop was also brought to completion. The latter was the principal effort in heat transfer during the quarter and features of the layout design are discussed at some length. Controls development work consisted of analytical studies including analog computer simulation of steady state control problems, completion of system start-up analysis studies, and some testing to supplement the analytical work on start-up. Reactor loop development results include pump tests and post-testing inspections, during which rupture and leak problems were encountered. Technical work on reactor loop controls was essentially completed during this quarter. Detail designs were prepared for test apparatus to prepare for investigation of creep of Cb-Zr alloys in contact with Li at SPUR operating temperatures. This work is still preliminary and modifications in the concept and apparatus design made during the period are discussed.

( ) 2-438 (Continued)

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AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5305-R;  
ASD-TR-61-656, Final Report, Nov. 1961. Contract AF 33(616)-7379.  
CONFIDENTIAL. A62-7487, Pt. 1.
2. "SPUR Phase I. Part 2: System design analysis and test results".  
AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5305-R;  
ASD-TR-61-656, Final Report, Oct. 1961. Contract AF 33(616)-7379.  
SECRET RESTRICTED DATA. A62-7487, Pt. 2.
3. "SPUR Phase I. Part 3: Reactor loop design analysis", by  
D. L. Cochran, et al. AiResearch Mfg. Div., Garrett Corp., Phoenix,  
Rept. no. SY-5305-R; ASD-TR-61-656, Final Report, Nov. 1962.  
Contract AF 33(616)-7379. SECRET RESTRICTED DATA.  
A62-7487, Pt. 3.
4. "SPUR Phase I. Part 4: Conversion loop, turbomachinery,  
electrical, and controls analysis", by L. E. Chadbourne, et al.  
AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5305-R;  
ASD-TR-61-656, June 1962. Contract AF 33(616)-7379.  
CONFIDENTIAL RESTRICTED DATA. A62-7487, Pt. 4.
5. "SPUR Phase I. Part 5: Conversion loop heat transfer analyses", by  
R. T. Caldwell, et al. AiResearch Mfg. Div., Garrett Corp.,  
Phoenix, Rept. no. SY-5305-R; ASD-TR-61-656. Oct. 1961.  
Contract AF 33(616)-7379. SECRET RESTRICTED DATA.  
A62-7487, Pt. 5.
6. "SPUR Phase I. Part 6: Materials evaluation summary", by  
E. A. Kovacevich, et al. AiResearch Mfg. Div., Garrett Corp.,  
Phoenix, Rept. no. SY-5305-R; ASD-TR-61-656, July 1962.  
Contract AF 33(616)-7379. SECRET RESTRICTED DATA.  
A62-7487, Pt. 6.
7. "Space power unit, reactor (SPUR) interim phase final report.  
Part I. Power conversion loop analysis and experiments".  
AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5377-R;  
ASD-TDR-62-711, June 1962. Contract AF 33(616)-8322.  
CONFIDENTIAL RESTRICTED DATA. A63-10, Pt. 1.
8. "Space power unit, reactor (SPUR) interim phase final report".  
Part 2. Reactor loop analysis and experiments". AiResearch Mfg.  
Div., Garrett Corp., Phoenix, Rept. no. SY-5377-R; ASD-TDR-62-711,  
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DATA. A63-10, Pt. 2.
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30 June 1962. AiResearch Mfg. Div., Garrett Corp., Phoenix,  
Rept. no. SY-5396-R1. 15 July 1962. UNCLASSIFIED. A62-7489.
10. "SPUR power system". Quarterly progress report. 30 Sept. 1962.  
AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5396-R2.  
15 Oct. 1962. Contract AF 33(657)-8954. A62-11457.

2-438 (Continued)

11. "SPUR power system, Phase II", by F. B. Wallace. Period ending 31 Dec. 1962. AiResearch Mfg. Div., Garrett Corp., Phoenix, Rept. no. SY-5457-R; Annual TSR, 31 Jan. 1963. CONFIDENTIAL. A63-2217.

2-439 STUDY NO. 4 FOR NAP SYSTEM REENTRY AND DISPOSAL PHENOMENA LIQUID-LAYER INSTABILITY AND DROPLET. Vidya, Inc., Sub. of Itek Corp., Palo Alto, Calif., Fourth Quarterly Progress Letter for the period 1 Oct. through 31 Dec. 1962, dated 23 Jan. 1963. Contract: AF 29(601)-5005, Proj. 1831, Task 183101. A63-1835.

Work done during the last quarterly reporting period is summarized with minimum technical detail. A final report is in preparation.

2-440 STUDY NO. 4 FOR NAP SYSTEM REENTRY AND DISPOSAL PHENOMENA LIQUID-LAYER INSTABILITY AND DROPLET. Vidya, Inc., Sub. of Itek Corp., Palo Alto, Calif., Eighth Monthly Progress Letter, dated 14 Dec. 1962. Contract: AF 29(601)-5005, Proj. 1831, Task 183101. A63-1836.

Work done during December 1962 is summarized. Six test runs were made. Preliminary results are given in the fourth quarterly progress letter, dated 23 January 1963.

#### NUCLEAR SOURCES OF ENERGY - CITATIONS ONLY

SNAP III. FINAL PERFORMANCE TEST SUMMARY. James D. Long. Martin Marietta Corp., Nuclear Div., Baltimore, Rept. no. MND-P-2398. Aug. 1960. 51p. illus. Contract: AT(30-3)-217. 6 refs. A63-1333.

## SECTION F - SOLAR SOURCES OF ENERGY

- 2-441 APPLIED RESEARCH PROGRAM ON HIGH-TEMPERATURE RADIATION-RESISTANT SOLAR-CELL ARRAY. Quarterly Technical Progress Report no. 3, Nov. 1962-Jan. 1963. Radio Corp. of America, Princeton, N. J., Astro-Electronics Div., Rept. no. AED 1816. 31 Jan. 1963. 49p. illus. Contract: AF 33(657)-8490, Task 817301-16. A63-2291.

During the third quarter, a total of 326 gallium arsenide cells were fabricated to meet the needs of the various temperature, radiation, and array design tests. A graph of frequency distribution versus cell efficiency for the third quarter is shown. A significant point is that during this period, the pilot line production peaked at a cell efficiency of about 8 percent. When this is compared with the peaks of the distributions for the first and second quarters production, it can be seen that a progressive improvement in the typical cell efficiency has been accomplished. Between the first and third quarters, the shift of the peak efficiency from 7 percent to 8 percent amounts to a net improvement of more than 14 percent. The factors contributing to this advancement are improvements made in every step of the process including operator supervision. A graph of frequency distribution versus cell efficiency for the total pilot line production through the third quarter is included.

- 2-442 DENDRITIC SILICON SOLAR CELL PANEL. Second Quarterly Technical Progress Report, 16 Nov. 1962-15 Feb. 1963. Westinghouse Electric Corp., Dayton. 13p. illus. Contract: AF 33(657)-9820, Proj. 8173, Task 817301-29. A63-4742.

Fabrication techniques on large area solar cells from silicon webbed dendrites are discussed in this report. Design considerations and fabrication techniques are presented. Several panels were fabricated and tested. Four panels were delivered to partly satisfy the requirement of the contract. Complete data is presented on these panels. A test program has been formulated to improve the efficiency of solar cells and to improve the design of solar panels. (Author)

- 2-443 ESTIMATE OF SPACE-RADIATION EFFECTS ON  
SATELLITE SOLAR-CELL POWER SUPPLIES.  
J. M. Denney, R. G. Downing, S. R. Lackman, and  
J. W. Oliver, (Space Technology Labs., Inc., Los Angeles).  
IRE Inst. (Radio Eng.), Trans. Military Electron.,  
MIL-6: 1 (Jan. 1962), p. 14-20.

The charged-particle intensity and energy distribution at the heart of the inner and outer Van Allen belts is compared with the experimentally determined radiation sensitivity of silicon solar cells. Energy dependence of the radiation damage and solar-cell characteristics is included in the life-time estimate of spacecraft solar cells. Use of charged-particle range-energy relations and the differential intensity of the Van Allen radiation results in an estimated effectiveness of thin protective shields. Comparative advantages of thin shields, advanced cell designs, solar efficiency, and solar-cell system over-design are discussed with respect to radiation resistance of spacecraft power supplies. (Author)

- 2-444 GALLIUM ARSENIDE SOLAR CELL PRODUCTION  
PROCESSES AND TECHNIQUES. H. Bertram, L. H. Gibbons,  
R. D. Gold, M. F. Lamorte, H. Meyers, S. Policastro,  
and L. West. Interim Technical Documentary Progress  
Report no. 2, 15 Oct.-15 Dec. 1962. Radio Corp. of America,  
Somerville, N. J., Semiconductor and Materials Div.  
24p. illus. Contract: AF 33(657)-8921. A63-3930.

The objective of this program is the development of production processes and techniques, and special tooling and equipment, for the fabrication of solar cells with a goal of better than 14 percent efficiency (10 percent minimum objective). Work was continued on improving the yield of single crystal gallium arsenide for solar cells in addition to supplying crystals for evaluation purposes. The many variables related to gallium arsenide crystal growth were studied in the continuing effort to optimize these conditions. Little correlation could be found between crystal yield and growth speeds, temperature gradients or bake-out conditions. A significant yield improvement was realized with the use of boats of smaller cross-sectional area and seeding for growth in the  $\langle 110 \rangle$  direction. Several steps in the solar cell fabrication process were carefully examined, with the view of either improving cell efficiency or increasing the potential production rate. Considerable attention was given to the means of applying solder contacts to the cell. To improve the quality of the present contact process, both the wafer and the lead alloy preform were cleaned in acid just prior to alloying the preform to the wafer. The peel strength of the lead alloy solder was determined. It can be concluded from these tests that the minimum breaking point of the material (2-mil solder with a contact line of 0.060") under ideal soldering conditions, is one pound and that higher values can be obtained by increasing the contact area for volume (i. e., by increasing build up of solder over the tab or wire). A study of resistance soldering techniques was undertaken in order to develop a controlled and reproducible bonding method. On the basis

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of preliminary work, it was concluded that the contact solder was compatible with cell interconnection techniques. Resistance soldering can be used to attach leads to the solar cell without using pre-tinned lead, flux, an inert or reducing atmosphere, excess heat, or solder buildup. The bond strengths thus obtained are superior to the strength of the solder layer itself. An investigation of polish etching showed that the presently used solution of hydrofluoric acid (4 parts) and hydrogen peroxide (22 parts) resulted in a fairly good polish but the texture of the wafer was pitted. Substitution of a sulfuric acid, hydrogen peroxide and water solution produced a much better surface polish but wafers were not as flat and time for polishing was one to two hours as compared to 5 minutes with the hydrofluoric acid solution. Infrared investigation of the anti-reflection coating revealed that under normal evaporation conditions the coating was a mixture of silicon monoxide and silicon dioxide. Temperatures between 100°C and 265°C caused a shift toward the silicon dioxide absorption band during the first 48 hours of exposure. After 350 hours of storage no additional shifting took place. The junction characteristics of a large number of pilot line cells have been determined. In some cases the ratios of the measured-to-calculated values of cell efficiency are quite low. If a grid structure contact with a greater number of stripes were employed, the power dissipation from the diode resistance would be reduced. However, the number of stripes cannot be arbitrarily increased because the stripes reduce the cell active area.

( ) 2-445 INVESTIGATION OF A 15-KW SOLAR DYNAMIC POWER SYSTEM FOR SPACE APPLICATION. K. E. Nichols. Interim Summary Report, 1 June 1960-1 June 1962. Sundstrand Aviation-Denver, ASD-TDR-62-1002. 1v. illus. Contract: AF 33(616)-7128, Proj. 3145, Task 30500. A63-1397.

This report covers Phase I of the 15-kw project during the period from 1 June 1960 to 1 June 1962. It summarizes the general design studies, detailed design efforts, conceptual experimental component fabrication, and development testing completed through the report period. The work was part of Phase I of the program, to prove feasibility of the concept. The evaluation and generation of design technology predominated. Experimental hardware components have been designed and their fabrication is in progress. A full scale design was created. It consisted of an inflatable concentrator, a solar energy divider, a double cavity heat receiver-storage unit, a multi-stage turbo-alternator assembly running on rubidium lubricated hydrodynamic bearings, and a radial flow radiator-condenser. Feasibility studies and designs were completed for an orientation system which minimizes reaction forces fed back to an assumed vehicle. Studies were

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completed for the integration and erection of the space power system (SPS) with an assumed vehicle. These last two items indicated the 15-kw SPS to be easily adaptable to a variety of vehicles and missions, on the basis of proposed booster and space vehicle volumes and diameters. First priority was given to proving feasible a large size solar concentrator. A design competition was staged between a folding rigid mirror and an inflatable type. During this competition, 10 foot diameter scale models of each were built and tested. The Goodyear inflatable foam-rigidized mirror was chosen and an extensive test evaluation made. The inflatable mirror appears to be feasible for space use in large sizes. Several flux traps were designed and tested. This device has not improved mirror efficiency as indicated by the preliminary analysis; however, its value is proven as a heat proportioner. A modified energy divider will be used in the double cavity heat receiver. The heat receiver-storage assembly remains the most critical element of the system. A small scale unit is being fabricated for future evaluation. The rotating assembly components, including an alternator which is expected to perform in rubidium vapor, are completed and they are being assembled. Special emphasis has been given the independent test of liquid metal bearings. A satisfactory test rig and preliminary thrust bearing data are being evaluated. Verification of the rubidium bearing design is not complete. Early tests of a segment of the full scale radiator condenser indicated this component performs satisfactorily. The development of instrumentation to measure both low and high pressures in rubidium vapor has been a major part of the program. Feasibility of the remaining components, with the exception of the mirror, will be determined. Final proof of mirror feasibility will have to be demonstrated with space tests.

Contents

Appendix A - Detailed Blading Design; Appendix B - Stress and Critical Speed Analysis; Appendix C - Flux Trap Analysis; Appendix D - Control Analysis

2-446 INVESTIGATION OF A 3 KW STIRLING CYCLE SOLAR POWER SYSTEM. Volume III. Solar Collector Analysis and Experimental Research. D. L. Dresser, E. H. Hietbrink, R. B. McClure, and R. O. Whitaker. Period covered: Sept. 1959-Aug. 1960. General Motors Corp., Indianapolis, Allison Div., Interim Report, WADD-TR-61-122, Vol. III. Jan. 1963. 262p. illus. Contract: AF 33(616)-6771, Proj. 3145, Task 30500. 79 refs. A62-5013, vol. 3.

This report summarizes work done in the field of solar collector systems for space applications. Various reflector designs are considered and the optical performance of several reflector geometries is compared. The effects of specular reflectivity, thermal gradients, and surface and orientation errors on the reflector performance is discussed. While several design procedures have been developed for predicting the performance and obtain-

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ing the maximum efficiency of practical solar collector components, no design procedure can be used with a sufficient degree of confidence until experimental data on large reflectors have verified the theoretical results. When all system requirements are considered, the electroformed Fresnel reflector is believed to be the best choice for space systems at the time of the report. An all-metal construction design has been completed. A nickel foil is electroformed onto a highly polished pattern; an electroformed nickel grid and support structure are then bonded to the foil and the assembly removed from the pattern. This results in a lightweight, foldable reflector. Continued development work is necessary to find better and cheaper ways of fabricating such reflectors. The major remaining area of uncertainty in reflector development is material reaction to the space environment.

2-447 IRRADIATION EFFECTS OF 22 AND 240 MEV PROTONS  
ON SEVERAL TRANSISTORS AND SOLAR CELLS.  
W. C. Hulten, W. C. Honoaker, and John L. Patterson.  
Langley Research Center, NASA, Hampton, Va.,  
TN D-718. Apr. 1961. 28p. illus. 3 refs.  
A61-5181.

The work covered in this report has been directed toward the investigation of the irradiation effects of 22 and 240 Mev protons on several transistors, solar cells, resistors, and condensers to be used in the space radiation environment. The experimental data indicated definite detrimental effects on transistors and solar cells but no apparent effects on the types of resistors and condensers tested. The detrimental effects are of two distinct types: transient and permanent.  
(Author)

2-448 LARGE AREA THIN FILM CADMIUM SULFIDE SOLAR  
CELL ARRAY INVESTIGATION. J. C. Schaefer,  
G. A. Wolff, and E. R. Hill. Second Quarterly Technical  
Progress Report, 15 Dec. 1962-15 Mar. 1963.  
Harshaw Chemical Co., Cleveland. 21 Mar. 1963.  
23p. illus. Contract: AF 33(657)-9975, Proj. 8173,  
Task 817301. 10 refs. A63-4534.

The effort for a large portion of this quarter has been directed toward the completion and testing of the four orbital test panels. No detrimental cell effects were noted. The panels were tested under tungsten light and sunlight, and were found to have efficiencies of 2.4 to 2.9% with power to weight ratios of 9.2 to 12.5 watts per pound. Various graphs indicating expected performance in space are included. Completion of this high priority effort permitted the emphasis to return to the research and development phases. Uniform coatings of CdS have been electrophoretically



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deposited on molybdenum substrates from nonaqueous solutions. New plastics and collector grid materials have been tested. Pole figure techniques are being applied to films deposited on various substrates to determine the effect of substrates on grain orientation. Studies of grain orientation have been continued using light-figure and x-ray diffraction techniques.

2-449 LES VEHICULES SPATIAUX A SOURCE D'ENERGIE SOLAIRE: "LE PROJET PHAETON" (In French). (Space Vehicles Using Solar Energy: Project Phaeton). M. Vernet-Lozet and G. de Clavier. Presented at Deuxième Symposium Spatial Européen, held 18-20 June 1962, Paris; sponsored by Société Française D'Astronautique and British Interplanetary Society. 10p. illus. TL782 V532.

Phaeton is a mercury Rankine solar power conversion system. The major components of the system include the deployable paraboloidal mirror which focuses solar energy into the cavity receiver. Lithium hydride provides the thermal energy storage required for sun-shade operation. This is very similar to the American Sunflower power conversion system. The Diamant will be used as the booster.

2-450 RESEARCH ON THIN FILM POLYCRYSTALLINE SOLAR CELLS. D. A. Cusano and M. R. Lorenz. Interim Scientific Report no. 1, 1 Sept.-31 Dec. 1962. General Electric Co., Auburn, N. Y. 23p. illus. Contract: AF 33(657)-10601, Task 817301-23. A63-3043.

The fabrication of solar cells from cadmium telluride was investigated. Cells were constructed from discs of single crystal CdTe in order to study the fabrication process independently of the techniques used to deposit polycrystalline films. The effects of variations in the fabrication parameters on the output voltage and current of the cells were measured. (The technique involves the formation of a copper telluride coating on a CdTe base by immersing it in a solution containing cuprous ions.) Cells were also constructed from thin films of polycrystalline CdTe in order to compare different deposition techniques. The following three techniques were investigated with the indicated results: (1) Sintering--cell efficiencies were very low, but not zero; (2) Hot wall evaporation--cell efficiencies 3 to 5 percent; and (3) Vapor reaction of platinum-coated porcelain substrates--resulting cells were small but good. The investigation into each technique is described in detail.

- ( 2-451 MARINER 2 SOLAR PANEL DESIGN AND FLIGHT PERFORMANCE. John A. Zoutendyk, Robert J. Vondra, and Arvin H. Smith. California Institute of Technology, Jet Propulsion Lab., Pasadena, No rept. no. 11 Apr. 1963. 77p. illus. Contract: NAS 7-100. 1 ref. A63-3395.

The electrical power for the Mariner 2 spacecraft which successfully completed a flyby of the planet Venus on December 14, 1962, was obtained from 10,710 boron-diffused, "P" on "N" silicon photovoltaic solar cells. The solar cells had dimensions of 1 - by 2-cm and were flat-mounted on two rectangular aluminum structures which provided a combined cell support area of 25.5 sq ft. The power drain from the solar panels to the spacecraft load ranged from 150 to 195 watts during the 130 days from launch until communication from the spacecraft was lost 21 days after Venus encounter. The Earth-to-space spectral correction factors for the two solar cell panels were 0.88 and 0.91. The temperatures at which the panels operated during the mission ranged from 45 to 120°C. Large power levels required for short time periods during the flight were supplied by energy storage batteries operating in conjunction with the two solar cell matrices, which hereafter are referred to as solar panels. The report discusses the design and flight performance of the solar panels.

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1. Zoutendyk, J.A., Solar-Cell Power Systems Testing, Technical Report No. 32-350, Jet Propulsion Laboratory, Pasadena, December 17, 1962.

- 2-452 RESEARCH ON IMPROVED SOLAR GENERATOR.  
Period covered: Oct. 1961-Oct. 1962. Westinghouse Electric Corp., Dayton, Final Report, ASD-TDR-62-1000. Jan. 1963. 109p. illus. Contract: AF 33(657)-7649, Proj. 8173, Task 817301-20. 8 refs. A63-3594.

Some of the basic theoretical considerations which govern the design and behavior of photovoltaic cells and the performance of solar cells were analyzed. The results of this analysis were utilized in a theoretical calculation of efficiency for a given set of cell parameters. The problems involved in growing (wider) silicon sheets and various furnaces used in the growing of webbed silicon dendrites are discussed. The main problem was to get wider silicon sheet consistent with uniform cross-sectional area. Feasibility of this was readily demonstrated. Further efforts are needed to get better control on these parameters, to render the process more versatile and adaptable to production methods. Solar cells have been successfully prepared on silicon webbed dendrites 1cm x 6" x 0.05cm and 1cm x 12" x 0.05cm respectively. Boron trichloride open-tube diffusion is found satisfactory in obtaining reproducible results for making high efficiency solar cells. Electroless nickel plating is found satisfactory to make contacts

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on the P and N side of the device. Efficiencies as high as 13.0% were achieved on 1 cm x 5" x 0.05 cm solar cells prepared on silicon webbed dendrites. Open circuit voltages of 0.59 volts and short circuit currents of 24 ma/cm<sup>2</sup> have been achieved on these cells. Effective shunt resistances have been considerably improved with the groove etching technique. This is attributed to the separation of the dendrites from the webbing. Weak alkali etches for removing the surface damage after initial sandblasting of the silicon webbed dendrite surface seem to be satisfactory in making high efficiency solar cells. Efficiencies as high as 12% and 10% have been achieved on 1 cm x 6" x 0.05 cm and 1 cm x 12" x 0.05 cm respectively. Prototype panels have been successfully fabricated using copper clad per mica sheets from solar cells prepared from webbed silicon dendrites. An operational panel consisting of 4 1 cm x 6" x 0.05 cm solar cells connected in series has been successfully fabricated using aluminum honeycomb substrate.

2-453 RESEARCH ON MATERIALS EXHIBITING PHOTOVOLTAIC PHENOMENA. James W. Burns. Period covered: June 1960-June 1962. Electro-Optical Systems, Inc., Pasadena, Final Report, no. 1571; ASD-TDR-62-841, Jan. 1963. 160p. illus. Contract: AF 33(616)-7482, Proj. 8173, Task 817301. 459 refs. A63-3424.

This report summarizes two years of effort directed toward the development of new materials for photovoltaic solar energy conversion. A brief review is given of the factors governing the selection of materials for efficient solar cells. Single crystals of p-type and n-type AlSb were grown by the Czochralski method. Purification of the available aluminum was found necessary. The purification and growth techniques are discussed in detail. Methods for slicing, lapping, etching, and electroding AlSb are also presented. The optical absorption coefficient of AlSb was determined in the spectral region from 0.55 to 2.0 microns, which includes part of the principal absorption band. In addition to the absorption edge at 0.8 microns, weak absorption bands are observed in p-type AlSb at 0.95 $\mu$  and 1.65 $\mu$ . Results are given for the Hall coefficient and carrier mobility in p-type AlSb as a function of temperature. The activation energy of the p-type impurity is 0.028 eV and the temperature dependence of the hole mobility  $T^{-2.2}$ . At 300°K, hole mobilities of 440 cm<sup>2</sup>/volt-sec. were measured. Junctions were formed in AlSb by diffusion of Se and Zn. Analysis of diode I-V characteristics, including temperature dependence, disclosed a recombination level 0.35 eV deep. The diffusion techniques and analysis of the diodes are described. Efficient AlSb solar cells were not fabricated because of residual impurities, and the fact that the junctions were not of the necessary quality. Preliminary studies were made of solid solutions of CdSe and CdTe, leading to evidence of the validity of Vegard's Law for these solutions. (Author)

2-453 (Continued)

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1. J. W. Burns, Second Quarterly Report, "Research on Materials Exhibiting Photovoltaic Phenomena," prepared for ASD, contract No. AF 33(616)-7482 (10 March 1961).
2. A. Herczog, R. R. Haberecht, and A. E. Middleton, "Research on Aluminum Antimonide for Semiconductor Devices," WADD Technical Report No. 57-631, AD No. 151144 (1958).
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2-454 RESEARCH ON THIN FILM POLYCRYSTALLINE SOLAR CELLS. D. A. Cusano and J. E. Lawler. Quarterly Technical Progress Report no. 2, 1 Jan.-31 Mar. 1963. General Electric Co., Auburn, N. Y. 23p. illus. Contract: AF 33(657)-10601, Task 817301-33. A63-4646.

Methods and techniques for fabricating thin film cadmium telluride solar cells were investigated. The films were grown on a variety of substrates. The cells fabricated from CdTe films on Molybdenum yielded conversion efficiencies of more than 2%. The open circuit voltage (OCV) and short circuit current (SCC) of such cells were measured. OCV's up to 0.495 volt and SCC's up to 15 ma/cm<sup>2</sup> were detected. The revamping of the vapor reaction apparatus used to deposit the films continued. The changes in design are described in detail. In addition, a study was made of the index of refraction of the films in order to determine the required index for a quarter wave anti-reflection coating. Measurements of SCC were made on several freshly prepared single crystal cells under solar illumination. Load characteristics were then taken with the indoor illuminator, adjusting the intensity was adjusted for the same SCC as measured in sunlight. Conversion efficiencies of 6.6, 6.8, and 7.5% were obtained for three good cells. The solar intensity was 97½ mw/cm<sup>2</sup>.

2-455 SOLAR ENERGY MEASUREMENT TECHNIQUES. Bernd Ross and D. B. Bickler. Period covered: Mar. 1961-31 Aug. 1962. Hoffman Electronics Corp., El Monte, Calif., Final Report, ASD-TDR-62-882. Jan. 1963. 167p. illus. Contract: AF 33(616)-7946, Proj. 8173, Task 817301-12. A63-4535.

This report describes a broad investigation which has been made of the subject of solar cell measurements. A portable tester has been designed and built which will enable an operator to determine the output of a solar

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cell power supply in space by analyzing output under conditions existing at either laboratory or field test sites. Painstaking experimentation and analysis of many alternatives has resulted in recommended optimum instrumentation and procedures for measuring solar cells and for performing the calibrations required. Calibrated primary standard solar cells have been provided in terms of their absolute spectral response. Data has been accumulated on the operational parameters of many solar cells using optimized measurement procedures. (Author)

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STUDY OF THIN FILM LARGE AREA PHOTOVOLTAIC  
SOLAR ENERGY CONVERTER. Warren J. Deshotels  
and Frank Augustine. First Quarterly Report, 1 Oct. -  
31 Dec. 1962. Clevite Corp., Cleveland, Electronic  
Research Div. 11 Jan. 1963. 19p. Contract:  
NAS7-203. 17 refs. A63-1764.

This First Quarterly Report gives a description of work done on cadmium sulfide solar cells by the Electronic Research Division of Clevite Corporation prior to the present contract. This includes a detailed description of the vacuum evaporation technique, the subsequent processing of the cadmium sulfide film into a solar cell, and the measurements performed on the completed cell to determine its efficiency and volt-ampere characteristics. This is followed by a discussion of the necessary requirements for "scaling-up" equipment and processes in order to accommodate the larger solar cells to be investigated under the present contract. Then specific experiments to determine optimum parameters are described followed by a brief discussion of alternate methods of producing cadmium sulfide solar cells. Finally, the present status of semiconductor photovoltaic theory applicable to cadmium sulfide solar cells is discussed, followed by a statement of work planned for the next reporting period. A new technique for depositing the  $\text{Cu}_2\text{O}$  layer has been developed. It has been found that a yellow gelatinous precipitate of  $\text{CuOH}$  can be decomposed into a red precipitate. The precipitate is predominately  $\text{Cu}_2\text{O}$  in the form of very small crystallites and may be sprayed on  $\text{CdS}$  films and processed into solar cells. With this technique heating or diffusion times as short as ten seconds are sufficient. A study of alternate methods of depositing  $\text{CdS}$  and/or  $\text{CdSe}$  films was initiated. This study will determine the feasibility of chemically depositing films from solution or by spray techniques. The work on lead sulfide involved techniques to deposit  $\text{PbS}$  mirrors on glass substrates. This was accomplished by rapid precipitation of  $\text{PbS}$  from a solution of a lead salt, thiurea and various complexing agents. First attempts to deposit  $\text{CdS}$  on glass yielded a powdery, not very adherent, discontinuous film of yellow  $\text{CdS}$  which could be deposited on frosted glass but not on smooth glass. Somewhat better results were obtained on a substrate of copper foil and when the foil was first dipped in a solution of indium chloride and air dried, then in the plating solution, a much better  $\text{CdS}$  film was obtained with a somewhat stronger photoeffect.

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2-457 THE THEORY AND APPLICATION OF SOLAR CELLS.  
W. W. Lloyd. Presented by Deuxième Symposium Spatial Européen, held 18-20 June 1962, Paris. 14p. 20 refs.  
TL796 L793.

This paper outlines the principle of photovoltaic action, the fabrication of silicon cells and mentions applications. A solar cell is a solid state photovoltaic device which converts radiant energy directly to electrical energy. Photovoltaic action is explained in terms of basic P-N junction theory. To summarize the theoretical considerations, an ideal material for solar energy conversion in space would have the following properties: Optimum reflection;  $E_g \approx 1.6$  eV to minimise spectrum and voltage loss;  $10^2 < \alpha(\lambda) < 10^5$ , where  $\lambda$  takes any value in the range 0.3 - 1.7 microns;  $L \approx 10^{-2}$  cm and  $s = 0$  to achieve maximum collection; resistant to electron and proton bombardment. In practice it may prove difficult to achieve this combination of parameters in a single material. Silicon is near ideal for sea level applications but efficiencies of only 10% have been achieved on a large scale so far. The fabrication of silicon solar cells basically consists of the following steps: The silicon wafer, obtained from a suitably doped single crystal is mechanically lapped to produce a flat undamaged surface.

The next step is to obtain a junction at a controlled depth on one side and a shallow diffusion, of the same type as the base material, on the other; the latter step is in order to reduce base contact resistances. The application of solar cells in satellites involves a detailed knowledge of the satellite orbit and angular motion. Since satellites are continually increasing in size and more electrically operated equipment is being put into them, the technique of placing the solar cells on extensible paddles has been developed. A popular size for individual cells is 2 x 1 cm. and these are usually formed into a shingle composed of 5 series connected cells. Note that as many parallel connections are made as is convenient in order to minimise the

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effects of failure of individual shingles. As to the land based applications, they may be divided into two main classes, detectors or sensors and energy converters. As detectors, the solar cells can be used to monitor light levels, read punched cards and generally contribute to automation. As energy converters, the solar cells are used in conjunction with storage batteries so that they become very attractive as a power source in inaccessible areas. Suitable applications are line repeaters, radio beacons, etc.

2-458 VARIABLE ENERGY GAP DEVICE. L. E. Stone and Geo. N. Webb. Setond Quarterly Technical Report, 1 Aug. - 1 Nov. 1962. Eagle-Picher Co., Miami, Okla. 30 Nov. 1962. 33p. illus. Contract: DA-36-039-SC-89106. 7 refs. A63-1643.

The general objective of this Contract is to investigate the variable band gap structure  $\text{GaAs}_x\text{-GaP}_{1-x}$ , having a gallium phosphide surface grading to lower energy gap GaAs below the surface and containing a single junction. The practical objectives are to establish the optimums of diffusion, doping, depths, contacting and techniques to produce the most efficient devices of this structure. Phosphorus diffusion schedules of  $900^\circ\text{C}$ -15 atmospheres, were found unsatisfactory and diffusion restricted to lower temperatures for two hours or less. A considerable number of variable gap and single gap cells were fabricated and tested. Studies of surface resistivity and carrier concentration as a function of zinc diffusion were carried out at temperatures of  $500^\circ\text{C}$ ,  $550^\circ\text{C}$ , and  $600^\circ\text{C}$ . Photo parameters were improved; diode characteristics were uniformly good. Chemical polishing of gallium arsenide wafers has been incorporated as a routine fabrication step. The etchant used for polishing was a sulfuric acid-peroxide solution. Open flow synthesis of gallium phosphide using elemental phosphorus and  $\text{Ga}_2\text{O}_3$  was successfully carried out. Dense growths of gallium phosphide needles were observed. Spectro-analysis indicate good purity. The needles are single phase gallium phosphide, of single crystal structure. Epitaxial growth of gallium phosphide layers on gallium arsenide substrates was carried out by two methods. The first method, using  $\text{Ga}_2\text{O}_3$  and elemental phosphorus in an open flow system is new for this purpose. The second method was by iodine transport in a closed system. Tentative results indicate both methods produced good epitaxial layers.



SOLAR SOURCES OF ENERGY - CITATIONS ONLY

ANALYSIS, FABRICATION AND TEST OF LARGE SOLAR CONCENTRATORS.  
Lee M. Springer. Fourth Quarterly Progress Report. Electro-Optical  
Systems, Inc., Pasadena, Rept. no. 1360-Q-4. 10 Mar. 1963. 20p. illus.  
Contract: AF 33(616)-8402, Proj. 3145, Task 60853-1, Item no. II.  
A63-2838.

LARGE AREA THIN FILM CADMIUM SULFIDE SOLAR CELL ARRAY  
INVESTIGATION. F. A. Shirland, J. C. Schaefer, G. A. Wolff, and  
E. R. Hill. First Quarterly Technical Progress Report, 15 Sept. -  
15 Dec. 1962. Harshaw Chemical Co., Cleveland, 4 Jan. 1963.  
36p. illus. Contract: AF 33(657)-9975, Proj. 8173, Task 817301.  
18 refs. A63-1630.

A NEW RADIATION-RESISTANT HIGH-EFFICIENCY SOLAR CELL.  
G. Mandelkorn, C. McAfee, J. Kesperis, L. Schwartz, and W. Pharo.  
U. S. Army Signal Research and Development Lab., Fort Monmouth,  
N. J., Rept. no. 2162. Oct. 1960. 10p. illus. AD 247 184.  
A63-2060.

RELIABILITY STUDY HIGH RATE LECLANCHE WAFER CELLS.  
Martin Sulkes. Final Report, 15 Apr. 1961 - 1 May 1962. United States  
Electric Mfg. Corp., N. Y. 9lp. illus. Contract: DA-36-039-SC-85266,  
Task 3A 99-09-002-02. A63-3232.

## SECTION G - THERMIONIC DEVICES

2-459      **ADVANCED SOLAR THERMIONIC POWER SYSTEMS.**  
Period covered: June 1960-Aug. 1962. Thompson Ramo  
Wooldridge, Inc., Cleveland, Final Report, ER-5038;  
ASD-TDR-62-877. Dec. 1962. 239p. illus. Contract:  
AF 33(616)-7411, Proj. 8173, Task 817305. A63-1601.

The primary objective of the Air Force program described in this report was to establish design criteria for advanced solar thermionic power systems in the 1-10 KW range suitable for application in aerospace vehicles. The program to accomplish this objective included a state-of-the-art survey of all system components as well as a comprehensive research, design, development, test and evaluation program directed toward advancing the art for thermionic converter and generators. At the time work on this program was begun, it was generally believed that both the close spaced vacuum and cesium vapor type thermionic converters held great promise for application in solar thermionic power systems. Efforts to develop the cesium converter had resulted in the attainment of nearly 500 hours of operation at watt densities of over 10 watts/cm<sup>2</sup> with calculated efficiencies of over 15% in experimental models. The vacuum close spaced units had been made to operate for only 20 hours at power densities of 0.4 watts/cm<sup>2</sup> at calculated efficiencies of 4.0%. This marked difference in performance, coupled with several still-unsolved structural problems associated with the close spaced converters, resulted in a recommendation to discontinue work on vacuum type converters. It was subsequently decided that two promising cesium vapor type thermionic generators would be evaluated during the remainder of the program. The first generator utilized two cylindrical geometry converters connected in series. Each converter was designed to produce 200 watts at 1 volt with 15% overall efficiency as the design objective. Converter no. 1 produced 160 watts at approximately .8 volts with a 10.6% efficiency. Converter no. 2 produced 200 watts at .8 volts with a 13.6% overall efficiency. Both converters were successfully operated in series with a combined output of 310 watts at 1.5 volts and an overall efficiency of 9.6%, as determined by the ratio of total electrical output to total electrical power input. The second generator configuration is called the cubical cavity generator because of the arrangement of five flat emitter faces to form a cubical cavity absorber. The sixth face of the cube served to admit flux from a solar concentrator. This generator was tested in the laboratory for over 72 hours and produced 122 watts at 3.7 volts with a 7.6% overall efficiency. In addition to the development and evaluation program carried out on the thermionic generators, the state-of-the-art in all other major component areas was subject to close examination. Components such as solar concentrators, orientation subsystems, energy storage systems, electrical controls and structural concepts were all carefully studied to determine what hardware and configurations might be applicable to a prototype thermionic power system at this time. Because of the temperatures associated with the efficient operation of thermionic

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generators, only precision, rigid type solar concentrators in conjunction with highly efficient cavity type solar receivers are suitable for solar thermionic power systems. Solar concentrator requirements and fabrication techniques perfected at this time indicate that only nickel electroformed concentrators are acceptable for a systems application. The state-of-the-art as it exists today limits the size of such concentrators to 5 feet in diameter, with reflectivities on the order of 89% being the best attainable. Development in the area of lightweight precision aluminum concentrators has shown much promise and may eventually replace the nickel concentrators at half the weight penalty, but to date such concentrators have not met the optical requirements for thermionic systems. It was immediately recognized that one of the major control areas associated with a thermionic power system is that of sun acquisition and tracking. Subsequent evaluation of generator and concentrator performance indicated an orientation of  $\pm 6$  minutes or better was actually required for the thermionic system. Also, because such a system was to be made of many module assemblies with attendant alignment problems because of the many hinge joints and structural members involved, some method of providing a fine orientation control for each module is required. A relatively simple mechanism called a heliotropic mount was evaluated to determine its ability to fulfill this need. The feasibility of the heliotropic orientation mechanism has been demonstrated. The further demonstration of its practical application with a thermionic module remains to be accomplished. Studies of the various techniques for energy storage, such as inertial, thermal and electro-chemical, indicate that only the latter is presently suitable for high-temperature thermionic system applications. Among the many electro-chemical storage systems, only two seem practical for a long-term orbital application. These two are nickel-cadmium and silver-cadmium storage batteries. Other areas, such as structures and deployment concepts, electrical systems controls, thermal controls, and orientation and start-up controls, are covered in detail. The state-of-the-art in these areas appears to be sufficiently advanced to meet the requirements of the thermionic power system. The results of all studies and developments were incorporated in a parametric design study and tempered with practical considerations and limitation in present day state-of-the-art hardware. As a result of all knowledge gained in the program, it has been established that the practical ranges for solar thermionic systems for orbital applications would seem to be for power ranges of from 200 watts to 3000 watts. This limitation is dictated by practical structural considerations. The Appendix of this report presents a detailed design, performance and test specification for a 1.5 KW, 28 volt continuous power system. The design presented has a specific weight of 440 lb/KW.

2-460

CAVITY VAPOR GENERATOR PROGRAM. D. L. Purdy,  
R. C. Keyser, F. A. Blake, and J. F. Williams.  
Period covered: June 1961-Sept. 1962. General Electric Co.,  
Philadelphia, Final Report, ASD-TDR-62-899. Dec. 1962.  
138p. illus. Contract: AF 33(616)-8394, Proj. 8173,  
Task 817305-14. 6 refs. A63-1864.

This report contains a description of the theoretical study, design, and test of a thermionic generator utilizing solar energy concentrated by means of a parabolic collector. In a successful feasibility demonstration, a multiple vapor-converter generator at the focus of a parabolic solar collector developed a peak power of 21.25 watts at 1.21 volts and 17.50 amps., at a cathode temperature of 1773°K, with all 3 converters operating in series. At a cathode temperature of 1668°K, 14.54 watts (.97 volts, 15 amps.) was obtained with 3 converters operating in series. At a cathode temperature of 1663°K, generator efficiency was 3.89%, excluding aperture losses. Overall efficiency was 2.02%. The test system consisted of a 5 foot diameter, 60° rim angle collector with a highly reflective coating, and a vacuum tank (12" diameter) through which the energy is transmitted. Test vacuum was approximately  $10^{-6}$  mm. There is a solar orientation system. Three vapor converters are positioned radially around the axis of the collector. Shoes welded to the converter cathodes form a cavity for solar energy absorption, and receive the concentrated solar energy. Heat shield insulation surrounds each converter. The converters are electrically insulated from the heat shield insulation by ceramic spacer rings and bushings. The molybdenum cathode is welded also to a cylindrical envelope, which contains the cesium. The cool side of the envelope is attached to a ceramic shield, which in turn is attached to the anode slug. Heat is rejected via a circular anode radiating fin. The cesium reservoir tube is exterior to the fin; its temperature is controlled by an electrical resistance heater.

2-461

CERAMIC TO METAL SEALS FOR HIGH-TEMPERATURE  
THERMIONIC CONVERTERS. First Quarterly Technical  
Report, 1 Oct.-31 Dec. 1962. Bendix Corp., Red Bank Div.,  
Eatontown, N. J., Rept. no. RBESO 3404-1. 15 Jan. 1963.  
35p. illus. Contract: AF 33(657)-10038, Proj. 8173,  
Task 817305. A63-1406.

The objective of this program is to develop seals which are capable of long life at 1500°C in cesium and vacuum environments, and to extend the sealing techniques developed to materials which are capable of long life at temperatures in excess of 1500°C. The project has been divided into four parts. Part I contains the following tasks: (A) Metallizing Process Studies. Several metallizing systems, which are basically moly-manganese modified by the additions of various activating materials, are being evaluated. Ceric oxide lithium manganate, manganese and titanium hydrides

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and titanium are among the activating materials being investigated. 96 percent alumina bodies are being used to determine the state-of-the-art; (B) Electron Beam Welding Studies. The feasibility of producing direct fusion joints between ceramics and refractory metals, and between the metallized surface of ceramics and refractory metals using electron beam welding techniques is being studied; (C) Ultrasonic Welding Studies. The feasibility study of using ultrasonic welding techniques to form a ceramic-to-metal seal was initiated; (D) Electroformed Seal Studies. The objective is to produce an electroformed hermetic seal of rhodium between molybdenum and molybdenum/manganese metallized alumina; (E) Diffusion Seal Studies. The objective is to produce vacuum-tight ceramic-to-metal seals between a refractory metal and a high purity ceramic by solid solution process; (F) Ceramic-composite Envelope Studies. The objective is to produce a cup-shaped envelope from a ceramic-metal composite material in which the material composition is graded from tungsten to ceramic.

2-462 CESIUM PLASMA STUDIES FOR THERMIONIC ENERGY  
CONVERSION. R. C. Knechtli and J. Y. Wada.  
Hughes Research Labs. Div., Hughes Aircraft Co.,  
Malibu, Calif., Final Report, No rept. no. June 1962.  
30p. illus. Contract: NOnr 3501(00), Task NR 09-358,  
Order no. 209-61. 5 refs. A63-1627.

A new method for measuring the volume recombination coefficient  $\alpha$  of thermal cesium plasmas in steady state has been devised and perfected. In this method, a thermal cesium plasma column is magnetically confined between two plasma generators. The plasma is generated by contact ionization and thermionic emission. The rate of plasma generation is controlled by the cesium vapor pressure in the device, the latter being directly measured in absolute value. The rate of plasma loss (in the range of measurement of  $\alpha$ ) is predominantly controlled by volume recombination, i.e., by  $\alpha$  and by the plasma density. The latter is measured by Langmuir probes. The recombination coefficient is then found as a function of the measured ion and neutral densities by equating the rates of ion generation and ion loss. The dynamics of plasma generation and loss in the apparatus described above has been analyzed in order to provide the relations needed for the determination of the volume recombination coefficient  $\alpha$  as a function of the measured ion and neutral densities. Interpretation of measurements performed at relatively low densities ( $n_+ < 4 \times 10^{12}$  ions/cm<sup>3</sup>) indicate as an auxiliary result of these investigations that the probability of surface recombination of cesium ions on tantalum or tungsten appears to be substantially lower than that predicted by the Saha-Langmuir equation. Within the accuracy of our method of measurement, the values of  $\alpha$  obtained in our experiments are in agreement with the values predicted by the theory of recombination by electron-electron-ion collisions. These seem to be the

( ) 2-462 (Continued)

first extensive measurements providing quantitative verification of this theory. These measurements then lead to the conclusion that recombination by electron-electron-ion collisions predominates within the ranges of plasma densities ( $10^{12}$  to  $10^{14}$   $\text{cm}^{-3}$ ) and degrees of ionization (5% to 90%) investigated. The numerical values obtained for  $\alpha$  also show that volume recombination is of negligible importance in the operation of cesium plasma thermionic energy converters. A modification of the apparatus used for the recombination measurements has led to the observation of low frequency oscillations in a cesium plasma column between a plasma emitter and a collector. A simple physical model explaining these oscillations has been evolved, and a mathematical analysis based on this model has been performed. General agreement between theory and experiment has been found, leading to a satisfactory explanation of these oscillations, which seem to be of the same nature as those observed in some cesium plasma thermionic energy converters. The results of our investigations thus lead to an appropriate explanation for these converter oscillations. (Author)

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1. R. C. Knechtli and J. Y. Wada, "Cesium Plasma Studies for Thermionic Energy Conversion," Semi-Annual Technical Summary Report, Contract No. Nonr 3501(00), October 1961.

( ) 2-463 DEVELOPMENT OF AN ENCAPSULATED THERMIONIC POWER GENERATOR. Quarterly Technical Progress Report, 1 Nov.-31 Jan. 1963. Martin Marietta Corp., Nuclear Div., Baltimore, Rept. no. MND-2945-1. 15 Feb. 1963. 5p. Contract: AF 33(657)-10077, Proj. 8173, Task 817305-20. A63-2204.

The engineering design of the double diode nuclear thermionic power generator has been completed. Fabrication of several component parts has been initiated. The parts for the  $\text{UO}_2$ -Mo fueled emitters are almost completely fabricated with only assembly and final machining remaining. The manufacture of other generator components including the collector temperature control assembly and the ceramic-to-metal seals has been initiated. The engineering design of the clad fuel elements has been completed and the first element, similar in configuration to the fueled emitter, has been fabricated. This element will be used to determine the changes in the vacuum emission characteristics over a 200 hour test period. The vacuum test chamber has been fabricated and is undergoing preliminary outgassing.

- 2-464 EXPLORATORY STATIC ENERGY CONVERSION STUDY-MULTILAYER THERMIONICS. W. J. van der Grinten. Second Quarterly Technical Progress Report, 1 Oct. - 31 Dec. 1962. General Electric Co., Syracuse. Jan. 1963. 26p. illus. Contract: AF 33(657)-9204, Task 817305-19. 4 refs. A63-1626.

The objective of this program is to demonstrate the suitability of solid state thermionics for the direct static conversion of heat to electricity. Several techniques for the depositions of thin germanium films, i.e., pyrolytic decomposition, evaporation, sputtering, and glow discharge have been considered. Sputtering has been used to produce 2000-16000 Å germanium films between tantalum, platinum, and gold electrodes. Difficulties encountered during the previous period with the measurements technique and the interpretation of results obtained have been overcome. Using a pulse type thermoelectric measurement technique, transverse p-type Seebeck voltages up to 6 microvolts have been recorded on these single layer samples. Reproducibility of results can and should be improved and quantitative measurements should also be extended to include germanium layers less than 2000 Å thick. The use of thin film electrodes facilitates voltage measurements under adverse conditions. Calculated diffusion into the germanium films appears to preclude the use of copper-, silver-, iron-, and even gold-electrodes for long-time high temperature exposures.

- 2-465 FEASIBILITY DETERMINATION OF A NUCLEAR THERMIONIC SPACE POWER PLANT. K. E. Buck, C. R. Fisher, and I. M. Rehn. Period covered: 1 Apr. 1961-31 Aug. 1962. Aerojet-General Nucleonics, San Ramon, Calif., Final Report, AN-700; ASD-TDR-62-827. Nov. 1962. 150p. illus. Contract: AF 33(616)-8119, Proj. 8173, Task 817305-10. 68 refs. A63-1300.

This report describes the first phase of a program to determine the feasibility of a nuclear space-power system that utilizes a thermionic radiator. In this concept, thermionic converters are mounted in the radiator of the power plant and lithium is circulated directly from the reactor through the radiator. Fins attached to the anode reject waste heat to space. The basic feasibility of the thermionic radiator concept was demonstrated. An electrically heated, refractory metal (Cb-1Zr) test loop which incorporated a centrifugal pump, thermionic converter, heat sink, and regenerator was constructed. Lithium was circulated to the thermionic converter at temperatures ranging from 2150° to 2260°F. A cylindrical thermionic converter (supplied by RCA) with a cathode surface area of 80 cm<sup>2</sup> was operated at power densities up to 1 watt/cm<sup>2</sup>. Limited systems analysis was also carried out in order to

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establish the potential specific performance of the power plant concept. A converter output of approximately 1.5 watts/cm<sup>2</sup> is needed to make the system competitive with advanced dynamic systems in terms of over-all system weight per unit of electrical output. While this power density is above that experimentally demonstrated in this program, it is very probable that a higher power density can be achieved with a reasonable developmental effort, and in a relatively short time. The primary advantages of this system appear to be: (1) low specific weight, (2) inherently high reliability and operating lifetime, and (3) low development cost. (Author)

2-466 FEASIBILITY DETERMINATION OF A NUCLEAR THERMIONIC SPACE POWER PLANT. Quarterly Technical Progress Report, 1 Nov. 1962-31 Jan. 1963. Aerojet-General Nucleonics, Sub. of Aerojet-General Corp., San Ramon, Calif., Rept. no. AN-856. 39p. illus. Contract: AF 33(657)-8977, Proj. 8173, Task 817305-10. A63-2241.

( ) The work described in this report is aimed at demonstrating operation of a minimum of three thermionic converters in series array heated by a liquid metal loop for a period of 1000 hours. At the close of this reporting period, the investigation of thermal bonding of converters to liquid metal tubing was complete. The technical approach in this portion of the effort is based on use of plasma-sprayed alumina as an electrical-insulating thermal-conducting material. Alumina is plasma-sprayed onto columbium tubing, then molybdenum is plasma-sprayed over the alumina. The bond is completed by brazing an outer molybdenum sleeve to the metallic coating on the alumina. Nickel, Ni-Mo-Fe and Ti alloys are suitable for use as brazing alloys for this purpose. Further screening is recommended on the basis of the diffusion rates of these alloys into Mo and alumina at operating temperatures (2200°F). Improved adhesion of the Al<sub>2</sub>O<sub>3</sub> coating to the Cb tubes is necessary for good thermal conductivity. Improved plasma spraying techniques or sintering the alumina coatings before brazing are possible approaches. Thermal transport analysis is in progress. Some results are reported in the work on heat rejection in a series of graphs. Reactor characteristics are also presented, on the assumption that a uranium carbide fueled, liquid-metal-cooled fast reactor operating at high temperature will be used. This work is continuing. For the series unit loop test, design of the test loop is essentially complete and fabrication is underway. This will be completed during the next quarter. A description of the design is given.

References

For preceding period, see AN-778 (A62-11614)

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- 2-467      **FEASIBILITY STUDY OF WATER-COOLED THERMIONIC NUCLEAR POWER PLANT.** Martin Marietta Corp., Nuclear Div., Baltimore, Rept. no. MND-2903, Volume I. Nov. 1962. 220p. illus. Contract: AT(30-1)-2990. 5 refs. A63-2205, vol. 1.

This volume contains a justification, description, and evaluation of a portable medium power type nuclear thermionic plant. A comparison among various concepts is made and a justification for the selected plant is given. A conceptual design of the selected plant is presented along with an evaluation of the characteristics and performance of this plant. The costs of building and operating the plant are based on the assumption that this plant is one of ten produced. A discussion of the results obtained and conclusions that may be drawn from these results and the studies conducted during the program is presented in a separate section. A series of appendices is included which describes in detail fuel element geometry, thermionic diode analysis, system control analysis, reliability and maintainability of this plant, and transportability of this plant. (Author)

- 2-468      **FEASIBILITY STUDY OF WATER-COOLED THERMIONIC NUCLEAR POWER PLANT.** Martin Marietta Corp., Nuclear Div., Baltimore, Rept. no. MND-2903, Volume II. Nov. 1962. 105p. Contract: AT(30-1)-2990. A63-2205, vol. 2.

This volume contains a description of the development program recommended to permit design and construction of a water-cooled thermionic plant. The entire program is divided into five areas: in-core diode development, both fuel element and thermionic diode; plant component development; critical experiments, both hot and cold; electrical converter; and engineering. The schedule, cost, scope, manpower, and facilities are defined for each of these five areas. The interrelations between programs and the applicability of each program to the design is shown. (Author)

- 2-469      **FIRST QUARTERLY REPORT FOR ADDITIVE CONVERTER STUDIES.** A. L. Hyland. Thermo Electron Engineering Corp., Waltham, Mass., Rept. no. 20-63. Mar. 1963. 14p. illus. Contract: AF 33(657)-10130. A63-3337.

This report outlines the background to and the progress of the first three months of the additive thermionic converter parametric investigation. The purpose of the investigation can be divided into two categories: (1) The quantitative determination of the effect on thermionic converter output, efficiency and surface emission characteristics due to the addition of fluorine, chlorine, and oxygen to the test chamber, and (2) The possible corrosive effect on converter construction materials of these additives. It is expected that the addition of the elements will materially increase the useful output and efficiency of the thermionic converter. It is also expected that the corrosive

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effects of these additives may be held to a minimum, such that the lifetime operation of the converter will not be unduly affected. The physical principles of a thermionic converter's operation can be summarized briefly as follows: An emitter maintained at a high temperature boils off electrons which are received by a collector held at a lower temperature. Cesium vapor is injected into the interelectrode space; cesium ions produced on the emitter surface reduce the work function of the emitter and neutralize the electron space charge. In order to be able to investigate the effect of additives on thermionic converter operation, the experimental vehicle must be provided with two separate reservoirs. The first contains the cesium; the second the additive. Each reservoir may be heated independently and the partial pressures of the constituents separately controlled to achieve the most advantageous emitter and collector coverage. It is important to determine the chemical effects of the additives on the construction materials of a thermionic converter. In order to measure these effects, a corrosion test vehicle has been designed. In order to be able to record correct temperature measurements during operation, a calibration relating observed temperature at the rear of the emitter to the temperature at the face of the emitter also was done.

2-470 FLAME HEATED THERMIONIC CONVERTER RESEARCH.  
W. R. Martini, R. L. McKisson, and R. G. Hoff.  
First Quarterly Report, 1 July-30 Sept. 1961.  
Atomics International Div., North American Aviation, Inc.,  
Canoga Park, Calif., Rept. AI-6815. 2 Apr. 1962.  
62p. illus. Contract: DA-36-039-SC-88982, Task  
3A99-09-002-04. AD 274 220. A62-12050.

TASK A - CONVERTER DEVELOPMENT. A nominal 150 w(e) electrically heated thermionic converter is being constructed. Such a large converter has not been made previously at this laboratory, but no unusual difficulties have been encountered. TASK B - HEAT SOURCE DEVELOPMENT. Two lines of development have been followed, in perfecting a furnace for heating thermionic diodes. One line of development has used laboratory compressed air and propane to attain thermionic temperatures and heat fluxes in a small combustion bed of zirconia chips. A furnace of this sort, called the demonstration furnace, has operated successfully many times. Using this furnace, a workable protective coating system for molybdenum was discovered (See Task C). The furnace is troubled with blockage of the fuel line due to coking, and with high heat losses, high stack losses, and a short lifetime for the furnace internals. The other line of development concerns furnaces employing aspirated air. These are now being sized to heat a converter like the one being built in Task A. Three designs were tested, each

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one better than the last. The best so far would heat a diode to 700°C with a heat flux of 9.5 w/cm<sup>2</sup>. A temperature of ~1500°C, and a heat flux of ~20 w/cm<sup>2</sup>, are required. TASK C - MATERIALS DEVELOPMENT. An apparently satisfactory protection scheme for molybdenum metal in a flame environment was discovered. The molybdenum metal is protected by a MoSi<sub>2</sub> coating. The MoSi<sub>2</sub> coating is protected from flame erosion by a thin barrier of SiC base refractory. Evaluation of MoSi<sub>2</sub> base coatings is well underway. One molybdenum wire, coated with a 0.0025-in. thick layer of Durak-B, withstood 1750°C in still air for 211 hr before the run was inadvertently terminated. TASK D - ELECTRICAL DEVELOPMENT. A survey of all possible inversion schemes was completed. Two methods appear to be practical for converting the output of one diode (1/2 v) to 12 v dc. One of these is a solid-state converter. At 1/2 v input, this converter is ~50% efficient, and weighs 0.2 to 0.3 lb/watt of output. The other is a novel type of motor-generator. It would operate as a hermetically sealed unit, with no possibility of radiating any radio noise. From preliminary designs, we estimate that it will be 75% efficient and weigh 0.08 to 0.10 lb/watt of output.

2-471      FOURTH QUARTERLY TECHNICAL PROGRESS REPORT  
ON INVESTIGATION OF THE MONOCAPILLARY  
THERMIONIC EMITTER AS A DUAL SOURCE OF IONS  
AND ELECTRONS. D. L. Dresser and W. Laurita.  
Period covered: 15 Aug. 1962-15 Feb. 1963.  
General Motors Corp., Indianapolis, Allison Div.,  
Rept. no. EDR 3207. 15 Feb. 1963. 120p. illus.  
Contract: AF 33(616)-8299, Proj. 8173, Task 817305.  
16 refs.      A63-3659.

Theoretical work is reported on a random current model of the capillary emitter--in this model the ion and electron emission currents are dependent upon the atom density at the capillary exit, and the emitter temperature. A solution of the cesium flow through a multi-capillary converter is obtained in order to estimate the interelectrode pressure. Experimental data on three multicapillary converters are reviewed. It is shown that the experimental data are in good agreement with the random current theory and flow solution. At the higher cesium temperatures the multi-capillary converter has a power density comparable to conventional converters because the interelectrode pressure is not negligible. Conclusions based on the results include the following: (1) The capillary in its present form is competitive with, but not superior to, the simpler designs of thermionic converters in the emitter temperature range from 1400 to 1800°K; (2) A modified form of the capillary as a hollow cathode structure with no flow-through of cesium may offer advantages in the temperature range from 1800 to 2200°K; and (3) Further study should be made of the

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form of a capillary emitter where the cesium is dispensed to the surface through a porous structure with pores of small diameter (less than 2 microns). Other investigators have reported complete ionization of cesium up to 15 ma/cm<sup>2</sup>. This emitter might be useful in low temperature converters with an emitter temperature range from 1400 to 1600°K. (Author)

References

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4. Reynolds, T. W. and Krebs, L. W. Gas Flow, Emittance, and Ion Current Capabilities of Porous Tungsten. NASA TN D-871, August 1961.

2-472 HIGH-TEMPERATURE VAPOR-FILLED THERMIONIC CONVERTER. W. Godsin. Quarterly Technical Progress Report, 1 Oct.-31 Dec. 1962. General Dynamics/Astronautics, San Diego, Rept. no. GA-3798. 7 Jan. 1963. 21p. illus. Contract: AF 33(657)-8563, Proj. 8173, Task 817305-5. A63-1745.

During the reporting period Cell F was operated at power for 484 hours. Cell F is the first cell in which the expected current emission density has been observed from a carbide emitter in an engineered thermionic generator. Short-circuit currents of 120 amp were observed from the emitter in the cell. A maximum power output of 50 watts (5 w/cm<sup>2</sup>) was obtained at an emitter temperature of 2440°K. During steady-state operation power was in the range from 10 to 30 watts. The cell was not optimized for maximum power. A considerable amount of data has been obtained on the separate effects of the cesium reservoir temperature and of the collector temperatures from which optimum power can be estimated. However, frequent filament failures during operation have interfered with plans to complete systematic optimization of all cell operating parameters. During the last month of this quarter the power output of Cell F had decreased to such an extent that it is planned to terminate this test after Cell G becomes operable. It is unknown at this time what the cause of decreased power output is. It appears that the quantity of cesium present in the cell is insufficient to maintain the required cesium density in the vapor phase. The construction of Cell G has been in progress during this reporting period and completion was scheduled during the period. A succession of leaks in the insulator, which first appeared in mid-December, has delayed the

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schedule. Also, during the final phase of Cell G construction, a short between the emitter and collector was discovered, necessitating a major repair. Cell bases H and J have been completed and baked out. Emitter No. 39 showed a satisfactory vacuum emission (1 amp/cm<sup>2</sup> at 2200°K). The emitter has been welded into the cell structure subsequent to the emission trials. During the next month the operation of Cells G and H is scheduled. Cell J will be completed as a stand-by unit. When Cells G and H become operational, series and parallel operation are planned.

2-473 KRYPTON FILLED THERMIONIC CONVERTER. R. Forman. Quarterly Technical Progress Report no. 1, 1 Jan.-31 Mar. 1963. Union Carbide Corp., Parma Research Lab., Cleveland. Apr. 1963. 17p. illus. Contract: AF 33(657)-10132. 4 refs. A63-4781.

Research work on irradiated inert gas thermionic diodes is presented. Tubes containing argon and krypton at various pressures in the range of about 100 torr were tested in the unirradiated condition and under high radiation conditions, including Co<sup>60</sup> gamma irradiation and the radiation from the core of a 5 megawatt swimming pool type reactor. Results showed that: (1) Maximum saturated current densities in the range of 0.1 - 0.2 amp/cm<sup>2</sup> were obtained from the diodes in the argon pressure range 60 - 100 torr. (2) The addition of small concentrations of xenon to argon appeared to cause early breakdown effects, but seemed to have no other significant effect on the general characteristics of the tube. Measurements on inert gas filled irradiated diodes with negative resistance characteristics are also discussed showing how such diodes can be used as a.c. generators over a range of frequencies up to 10 megacycles.

2-474 LONG-LIFE THERMIONIC CONVERTERS FOR SOLAR POWER SYSTEMS. Period covered: Mar. 1961-Oct. 1962. TAPCO Div., Thompson Ramo Wooldridge, Inc., Cleveland, Final Report, ER-5137; ASD-TDR-62-1069. Feb. 1963. 82p. illus. Contract: AF 33(616)-8114, Proj. 8173, Task 817305-4. A63-3605.

This report describes the work accomplished under an applied research program directed toward increasing the cycle life of thermionic converters which can be used in solar thermionic generators. The results of cycle life tests of five thermionic converters, and the results of a solar test of a cavity-type thermionic generator which used five converters identical to the life test converters, are presented. A complete discussion of all specialized equipment and techniques is also included along with design details. Cycle Life Test Program. The number of cycles achieved on the five life test converters is the greatest number reported to date in the liter-

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ature. The severe thermal cycling undergone by each of the converters attests to the fact that an advance in the state-of-the-art of fabrication of high temperature thermionic converters has been accomplished, however, greater cycle life capability of converters must be demonstrated before thermionic converters can be relied upon for operation for periods as long as one year. The current metallographic analysis of a converter which performed satisfactorily for 397 cycles (596 hours) as well as the continuing thermal cycling of two converter assemblies will permit improvements in design of future converters. Sustained performance evaluations of redesigned converters have been recommended. Such evaluations will result in further advances in the art of fabrication of converters having increased life and performance capabilities. These converters can then be incorporated in thermionic generators having improved reliability. Solar Test Program. Although the solar test program was limited in scope, a substantial amount of data was acquired during the flux profile, cavity power distribution, and cubical cavity generator tests. Unfortunately, the solar constant at the test site during the solar test of the generator was not sufficiently high to permit operation at generator output levels, which could confidently be compared with the laboratory performance data. An extrapolation of data was, therefore, required in the correlation. The cubical cavity generator was still operable at the conclusion of the scheduled tests and recommendations have been made to acquire additional solar performance characteristics of the generator at a test site where solar constants in the range of 85 to 100 watts/ft<sup>2</sup> would be available to the solar energy collection system. Further study of the thermal response characteristics of the generator at higher input flux levels, as well as effects on generator performance and cavity power distribution under misoriented concentrator conditions, have been recommended. The orientation errors can be introduced as persistent errors and as cyclic errors to simulate the rocking or oscillation of a space vehicle. This information would allow the accuracy of the vehicle attitude control and/or orientation system control to be established. Based on the information acquired and evaluations accomplished to date, recommendations and design concepts for an advance cavity-type solar thermionic generator have been proposed for additional solar evaluations. The proposed design is sized to permit sustained operation at a design temperature of 2000°K in the solar test facility described in this report.

- 2-475 THERMIONIC CONVERTER RESEARCH. R. Laubenstein, W. Beyermann, and B. Chang. Rept. no. 6. Second Quarterly Progress Report, 1 Oct.-31 Dec. 1962. Marquardt Corp., Van Nuys, Calif., Rept. no. 25,066. Jan. 1963. 40p. illus. Contract: DA 36-039-SC-90751 (Continuation of Contract DA 36-039-SC-87217), Task 3A99-13-003-02. 6 refs. A63-3870.

Neutralization of electron space charge by means of positive ions emitted from a heated alkali salt has been studied in a three-electrode apparatus consisting of an electron emitter, a collector, and an ion emitter electrode. Space-charge neutralization was observed, but the efficiency of positive ions for neutralization was disappointingly low with the configuration studied. Optimum electrode spacings and ion-emitter bias voltages were found to depend on the collector voltage. The performance of a thermionic converter with molybdenum electrodes has been studied for emitter temperatures from 1100°C to 1450°C. Maximum power output data with 10-mil and 19-mil spacings between electrodes intersect at an emitter temperature of about 1200°C. Below this temperature the 19 mil spacing yields higher output power, whereas, for higher emitter temperatures the 10-mil spacing yields higher output power. Converters with a molybdenum emitter were found to have better performance during the early part of their life than after several days of operation. After about 6 days of operation, the maximum power output was observed to have decreased by about 50 percent and no further degradation in performance was observed. The effect of variations of cesium pressure and collector temperature on converter performance was studied. The optimum cesium-reservoir temperature is sensitive to converter operating parameters including small values of resistance in the electrode leads. (Author)

#### References

1. K.G. Hernqvist, "Plasma Synthesis and its Application to Thermionic Power Conversion", RCA Review, Vol. 22, p. 7, March 1961.
2. F.M. Johnson, "Studies of the Ion Emitter Beta-Eucryptite", RCA Review, Vol. 23, p. 427, (September, 1962).
3. R.A. Laubenstein, W. Beyermann, and B. Chang, "Thermionic Converter Research", Report No. 5, First Quarterly Report, 1 July 1962 through 30 September, 1962, Marquardt Report No. 25,060 (Oct., 1962).
4. N.S. Rasor and C.C. Weeks, "Thermionic Converters for Compact Nuclear Power Plants", NAA-SR-7144 (August, 1962).
5. S.S. Kitrilakis, M.E. Meeker and N.S. Rasor, "Annual Technical Summary Report for the Thermionic Emitter Materials Research Program", Report No. 2-63 or TEE4015-3 (no date).

## SECTION H - THERMOELECTRIC DEVICES

- 2-476 HIGH TEMPERATURE THERMOELECTRIC GENERATOR.  
C. M. Henderson, R. G. Ault, Emil Beaver, and  
H. B. Jankowsky. Period covered: 30 Sept. 1961-  
30 Sept. 1962. Monsanto Research Corp., Dayton,  
Final Report, ASD-TDR-62-896. Oct. 1962. 81p. illus.  
Contract: AF 33(657)-7387, Proj. 8173, Task 817302-9.  
A62-12509.

Research and development of a laboratory type high-temperature thermoelectric generator having a nominal output of 5 watts at a hot-junction temperature of 1200°C and a cold-junction temperature of 700°C in a vacuum is described. Based on the modular concept, the generator is comprised of 9 series-connected sections of three parallel-connected modules each. The modules are made of MCC 50, a proprietary thermoelectric material, joined to graphite junctions. Research leading to development of this type module is described. Sublimation losses for MCC 50 were less than 1% during 1000 hours at 1200°C and a vacuum of greater than  $10^{-5}$  mm Hg. The generator was operated under these conditions for 100 hours continuously and then withstood 106 thermal cycles from ambient temperature to 1200°C without a failure.

- 2-477 HIGH TEMPERATURE THERMOELECTRIC GENERATOR.  
C. M. Henderson, R. G. Ault, Emil Beaver,  
R. J. Janowiecki, H. B. Jankowsky, and L. Reitsma.  
Fourth Quarterly Progress Report, 1 Oct. -31 Dec. 1962.  
Monsanto Research Corp., Sub. of Monsanto Chemical Co.,  
Dayton. 47p. illus. Contract: AF 33(657)-7387,  
Proj. 8173, Task 817302-9. A63-1567.

The overall program objective is to conduct applied research to establish the technical feasibility of utilizing a high temperature thermoelectric generator with a nuclear reactor heat source to produce a long-lived power supply for aerospace vehicles. This quarter the experimental model generator completed 804 hr of operation at a hot end temperature of 1200°C (+25°C, -0°C) in a vacuum of  $10^{-5}$  mm Hg without degradation of its power producing characteristics. In fact, the power output of this unit improved slightly during this period. This sustained performance test is continuing. Progress was made in efforts to improve the properties of MCC 60, a proprietary n-type high temperature thermoelectric material, so that it will match the properties of MCC 50. Materials for modifying MCC 50, MCC 60, and MCC 40 (a proprietary material for use below 850°C), were procured



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and initial investigations to improve the properties of these materials were made. Investigations were initiated to develop an improved emissive coating to increase the rate of heat rejected to space by the advanced experimental model generator. Several MCC 50-graphite modules were fabricated using an arc-plasma spray coating technique.

References

1. See Preceding Reports of this Series
2. "High Temperature Thermoelectric Generator". Monsanto Research Corp., Dayton, Ohio, ASD-TDR-62-896, October 1962. Contract AF 33(657)-7387. A62-12509.

2-478 HIGH TEMPERATURE THERMOELECTRIC RESEARCH.  
C. M. Henderson. Fifth Quarterly Progress Report,  
1 Jan. -29 Mar. 1963. Monsanto Research Corp., Sub. of  
Monsanto Chemical Co., Dayton Lab., Dayton. 42p. illus.  
Contract: AF 33(657)-7387, Proj. 8173, Task 817302-9.  
A63-4976.

An experimental model 5-watt (nominal) generator completed 2556 hrs of a sustained performance test at a hot-end temperature of  $1200^{\circ}\text{C}$  ( $+25^{\circ}\text{C}$ - $4^{\circ}\text{C}$ ), cold end at  $714^{\circ}\text{C}$  ( $+12^{\circ}\text{C}$ - $0^{\circ}\text{C}$ ), in a vacuum of  $10^{-5}$  -  $10^{-6}$  mm Hg without degradation in power producing characteristics. The power/weight ratio of this generator, exclusive of heat source, ranged from 2.70 to 2.86 watt/lb. Tests at  $1300^{\circ}\text{C}$  and higher temperatures will be attempted with this generator. Graphite-ended segmented modules of n- and p-type thermoelectric materials to supplement p-type MCC 50, a proprietary thermoelectric material used in the 5-watt generator, were fabricated and partially evaluated. The first such p-n couple produced 250% more power than the p-type MCC-molybdenum couple used in the 5-watt generator. Improved emissive coatings and lightweight junctions between modules were produced. These developments suggest that an advanced experimental 50-watt generator having a power/weight ratio of 10-20 watt/lb is feasible. For preceding period see Fourth Quarterly Progress Report (A63-1567).

2-479 SOLAR THERMOELECTRIC GENERATOR SYSTEM CONCEPT AND FEASIBILITY STUDY. A. J. Krause, J. L. McCabria, and D. A. Naumer. Quarterly Report no. 4, 15 Nov. 1962-15 Feb. 1963. Westinghouse Electric Corp., Lima, Ohio. 15 Feb. 1963. 47p. illus. Contract: AF 33(657)-8089, Proj. 8173, Task 817302-10. A63-3593.

The objective of this project is to accomplish a theoretical, analytical, and experimental applied research program to establish and prove the feasibility of a solar thermoelectric generator system concept for future advanced space flight vehicles. A feasibility model has been assembled and tested

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in a simulated altitude chamber. Twenty-eight hours of operation were accumulated during these tests. The model was subjected to three start-ups and shut-downs. Twelve warm-up and cool-down cycles (including start-ups and shut-downs) were accumulated. The last nine cycles were imposed consecutively. It can be concluded from the results of the simulated space environmental tests that: (1) The generator was capable of generating power continuously for 90 minutes with a 55 minute power-on period and a 35 minute power-off period. This was successfully accomplished with an input power of 575 watts. The average output of the generator over the 90 minute period was 12.0 watts. The maximum power output during the 90 minute cycle was 7.2 percent greater than the mean output. The minimum power output was 6.9 percent less than the mean output. The calculated cycle efficiency for these conditions was 3.42 percent; (2) The power output of the generator decreased after two modules or the equivalent of two modules (one-sixth of the total modules) were short-circuited. The estimated output of the generator with out the short-circuit condition is 14.4 watts (average over 90 minute cycles). The power input required for 14.4 output would be 558 for 55 minutes. The calculated efficiency for these conditions is 4.22 percent; (3) The mean load voltage output of the generator for the condition discussed in part one above was 8.21 volts over the 90 minute period. The maximum voltage was 4.7 percent greater than the mean and the minimum was 4.0 percent less than the mean. The estimated mean voltage output of the generator with out the short-circuit condition is 9.85 volts; (4) The temperature measurement of the thermal storage container indicates that both latent heat and sensible heat of the LiH was utilized for energy storage. At the end of the cool-down portion of the cycle, the temperature of the walls of the container adjacent to the module were approximately 80°F below the melting point of LiH. At this time the temperature of the walls adjacent to the heater block were approximately equal to the melting point of LiH. Thus, at the end of cool-down portion of the cycle, all of the LiH was in the solid phase and somewhat below the melting point. At the end of the warm-up portion of the cycle the temperature of the walls adjacent to the module was slightly above the melting point of LiH and the temperature of the walls adjacent to the heater was several degrees above the melting point. Thus, at the end of the warm-up portion of the cycle, all of the LiH was in the liquid phase and some sensible heat was stored in the liquid. The wall of the storage container adjacent to the modules varied approximately 90°F over the 90 minute cycle. The mean average temperature of this wall was approximately 40°F below the melting point of LiH; and (5) The hot and cold junction temperatures as well as the cold strap and radiator temperature varied in the same manner as the energy storage container. The variation of temperature on the cold side of the generator was less than the variation on the hot side. The carnot efficiency based

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in a simulated altitude chamber. Twenty-eight hours of operation were accumulated during these tests. The model was subjected to three start-ups and shut-downs. Twelve warm-up and cool-down cycles (including start-ups and shut-downs) were accumulated. The last nine cycles were imposed consecutively. It can be concluded from the results of the simulated space environmental tests that: (1) The generator was capable of generating power continuously for 90 minutes with a 55 minute power-on period and a 35 minute power-off period. This was successfully accomplished with an input power of 575 watts. The average output of the generator over the 90 minute period was 12.0 watts. The maximum power output during the 90 minute cycle was 7.2 percent greater than the mean output. The minimum power output was 6.9 percent less than the mean output. The calculated cycle efficiency for these conditions was 3.42 percent; (2) The power output of the generator decreased after two modules or the equivalent of two modules (one-sixth of the total modules) were short-circuited. The estimated output of the generator with out the short-circuit condition is 14.4 watts (average over 90 minute cycles). The power input required for 14.4 output would be 558 for 55 minutes. The calculated efficiency for these conditions is 4.22 percent; (3) The mean load voltage output of the generator for the condition discussed in part one above was 8.21 volts over the 90 minute period. The maximum voltage was 4.7 percent greater than the mean and the minimum was 4.0 percent less than the mean. The estimated mean voltage output of the generator with out the short-circuit condition is 9.85 volts; (4) The temperature measurement of the thermal storage container indicates that both latent heat and sensible heat of the LiH was utilized for energy storage. At the end of the cool-down portion of the cycle, the temperature of the walls of the container adjacent to the module were approximately 80°F below the melting point of LiH. At this time the temperature of the walls adjacent to the heater block were approximately equal to the melting point of LiH. Thus, at the end of cool-down portion of the cycle, all of the LiH was in the solid phase and somewhat below the melting point. At the end of the warm-up portion of the cycle the temperature of the walls adjacent to the module was slightly above the melting point of LiH and the temperature of the walls adjacent to the heater was several degrees above the melting point. Thus, at the end of the warm-up portion of the cycle, all of the LiH was in the liquid phase and some sensible heat was stored in the liquid. The wall of the storage container adjacent to the modules varied approximately 90°F over the 90 minute cycle. The mean average temperature of this wall was approximately 40°F below the melting point of LiH; and (5) The hot and cold junction temperatures as well as the cold strap and radiator temperature varied in the same manner as the energy storage container. The variation of temperature on the cold side of the generator was less than the variation on the hot side. The carnot efficiency based

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upon hot and cold junction temperatures remained fairly constant ( $40 \pm 1$  percent) over the entire cycle. It is therefore logical to conclude that the efficiency of conversion within the thermopile remained fairly constant over the entire cycle.

References

1. Krause, A. J., et al, "Solar thermoelectric generator system concept and feasibility study", Quarterly Progress Report nos. 1, 2, and 3, 15 Feb.-15 Nov. 1962. Westinghouse Electric Corp. Contract AF 33(657)-8089.

THERMOELECTRIC DEVICES - CITATIONS ONLY

STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR POWER SOURCE FIVE-WATT U. S. NAVY WEATHER STATION. Martin Marietta Corp., Nuclear Div., Baltimore, Final Report, MND-P-2707. Not dated. 99p. illus. Contract: AT(30-3)-217. 12 refs. A63-1332.

STRONTIUM-90 FUELED THERMOELECTRIC GENERATOR DEVELOPMENT. W. S. West. SNAP 7 Program Quarterly Progress Report no. 4, 1 Aug.-31 Oct. 1961. Martin Marietta Corp., Nuclear Div., Baltimore, Rept. no. MND-P-2483-4. 108p. illus. Contract: AT(30-3)-217, Task 8. 8 refs. A63-1718.

II. MATERIALS

## SECTION A - GENERAL

- 2-480 BIBLIOGRAPHY AND TABULATION OF DAMPING  
 PROPERTIES OF NON-METALLIC MATERIALS.  
 Sun Hwan Chi. Period covered: June 1957-Sept. 1960.  
 University of Minnesota, Minneapolis, Final Report,  
WADD-TR-60-540. Sept. 1962. 147p. illus.  
 Contract: AF 33(657)-7453, Proj. 7351, Task 735106.  
 200 refs. A62-12081.

This bibliography was compiled as an aid for those people interested in damping research and related fields. It contains a nearly complete list of references on the damping properties of non-metallic materials for the period from 1929 to 1959, together with an index of nomenclature, units, and test methods. Tabulations of the in-phase and out-of-phase components of Young's modulus and the shear modulus for the various materials are also shown, and graphical representations of experimental data indicate the loss factor values for different materials. Those values of the loss factor are compared to those of the representative structural metals. A detailed code classification system for the field of damping is also described, and an abstract of each referenced article together with a coded supplement is also included in this report. The code is provided to aid those using the ASM-SLA punched-card system. (Author)

- 2-481 CRITERIA FOR RUPTURE OF CERTAIN TEXTILE  
 STRUCTURES UNDER BIAXIAL STRESS. Peter Popper.  
 Period covered: Jan.-June 1962. Aeronautical Systems Div.,  
Wright-Patterson AFB, Ohio, Directorate of Materials  
and Processes, Final Report, ASD-TDR-62-613.  
 Aug. 1962. 17p. illus. Proj. 7320, Task 732002.  
 4 refs. A62-12539.

This report outlines a procedure for determining the combinations of biaxial stress which will cause failure in certain types of fabrics. Solutions are given for knitted fabrics and "diamond" structures, and are presented in the graphical form of a rupture envelope. Also, a commonly used rupture criteria for solid materials is included for comparison with the graphic results. (Author)

2-481 (Continued)

References

1. Popper, P., The Theoretical Behavior of a Knitted Fabric Subjected to Biaxial Stresses. ASD Technical Documentary Report Nr WADD-TR-60-897. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, July 1961.
2. Mellen, D.M., Backer, S., and Park, B.J., Research on Materials for Use in Full Pressure Suits. ASD Technical Documentary Report Nr WADD-60-311. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, December 1960.
3. Popper, P., The Design of Materials for Full Pressure Suits. Thesis, Textile Division, M.I.T., 1960.

2-482 EVALUATION OF COATING SYSTEMS FOR HIGH STRENGTH, LOW ALLOY STEEL EXTERIOR MISSILE AND ROCKET CASINGS. H. R. Nelson and K. E. Hofer. Period covered: 3 Jan. 1961-28 Feb. 1962. Armour Research Foundation, Chicago, Final Report, ASD-TDR-62-421. May 1962. 66p. illus. Contract: AF 33(616)-7739, Proj. 7381, Task 738101. A62-11118.

Existing organic coating systems were evaluated by exposing coated specimens to environments to which missile and rocket casings may be exposed during fabrication, storage, shipment, and readiness. SAE 4340 steel was the substrate material. The protection afforded the substrate was evaluated by direct tests of the coatings or by the change in the performance of the coating or substrate following exposure to various adverse environments. Sixteen systems were studied. Tension, fatigue, embrittlement, abrasion, adhesion, flexibility, stress-corrosion, thermal change and humidity, accelerated weathering and salt spray corrosion were the tests made. (Author)

2-483 INVESTIGATION OF BORIDE COMPOUNDS FOR VERY HIGH TEMPERATURE APPLICATIONS. Larry Kaufman. Semiannual Report no. 1. Manlabs, Inc., Cambridge. Oct. 1962. 1v. illus. Contract: AF 33(657)-8635. 68 refs. A62-11167.

The initial group of borides selected for the present study include the fully dense, high-purity diborides  $TiB_2$ ,  $ZrB_2$ ,  $NbB_2$  and  $TaB_2$ . Some progress in preparing single crystals  $NbB_2$  was achieved and results show that the zone melting operation will be used. Studies of high pressure hot pressing and sintering behavior have begun. It is anticipated that the utilization of pressures of twenty kilobars (300,000 psi) and high temperatures can be used to achieve fine grained specimens of the diborides. The physical and mechanical characteristics of the diborides as a function of temperature up to 1500°C will be determined. Measurements at higher

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temperature will be performed in a later phase of the program after oxidation and thermodynamic data sufficient to describe the high temperature behavior are available. X-ray hot hardness, oxidation, vapor pressure and phase boundary measurements will be made. The available specific heat data and information on the heat of formation of diborides has been collected and integrated. It is suggested that a portion of the discrepancy between the heats of formation values suggested in the literature stems from the usual assumption that  $\Delta C_P = 0$ . A detailed discussion of the case for  $ZrB_2$  shows that this assumption can lead to differences in the enthalpies of formation as determined by various techniques. The Schottky-Wagner model for the thermodynamic properties of a nonstoichiometric compound has been applied to the diborides in order to define: the vapor pressures of the metal and boron atom as a function of temperature and composition, the conditions for congruent vaporization, and the phase boundaries all in terms of three parameters. These parameters which include the intrinsic vacancy concentration and the free energy of formation of metal and boron vacancies have been estimated for  $TiB_2$ .

2-484 A MATRIX METHOD FOR THE ANALYSIS OF THE BUCKLING OF STRUCTURAL PANELS SUBJECTED TO CREEP ENVIRONMENTS. D. S. Warren. Period covered: July 1961-June 1962. Douglas Aircraft Co., Santa Monica, Calif., Final Report, LB-31023; ASD-TDR-62-740, Nov. 1962. 181p. illus. Contract: AF 33(616)-8359, Proj. 1467, Task 146701. 22 refs. A63-1648.

A method for the analysis of the buckling of plane structural panels subjected to creep environments is presented and evaluated. The method is written matrixially for simplified programming for a modern digital computer installation. A suitable sequence of computer operations is described in detail. The sequence of computer operations includes an automatic, iterative solution of the nonlinear matrix equation for large deflections; the effects of both short-time and time-dependent plastic deformations are included via a semi-automatic, incremental approach. The method is formulated for the general case of initial eccentricities, and their effects are explicitly described. The limiting case of a structure without initial eccentricity can be investigated on the basis of an eigenvalue definition available at an early stage of the computing process. Test-theory comparisons are presented for a series of structural panels subjected to eccentric, in-plane, compressive loading and elevated temperatures. It is concluded that the method is economically practical and theoretically sound. For cases of elastic and short-time plastic deformations, the method should be of immediate practical value throughout the industry. Major improvements in the precision of available creep data are required for exploitation of the method in the analysis of cases involving creep. (Author)

2-484 (Continued)

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1. Lansing, W., Jones, I. W. and Ratner, P.: "A Matrix Force Method for Analyzing Heated Wings, Including Large Deflections", ACR-62, Volume One, Symposium Proceedings, Structural Dynamics of High Speed Flight, April 1961.
2. Warren, D. S., Castle, R. A., and Gloria, R. C.: "An Evaluation of the State-of-the-Art of Thermo-Mechanical Analysis of Complex Structures", WADD Technical Report 61-152, May, 1961.
3. Christensen, R. H. and Denke, P. H.: "Crack Strength and Crack Propagation Characteristics of High Strength Metals", ASD-TR-61-207 January 1962.

2-485 RADIATION CHEMISTRY OF BENZENE SOLUTIONS OF ORGANOMETALLIC COMPOUNDS OF THE TYPE  $M(C_6H_5)_n$ . M. Burton and D. B. Peterson. (This report covers work ending 30 June 1962). University of Notre Dame, Notre Dame, Indiana, Final Report, ASD-TDR-62-875. Oct. 1962. 24p. illus. Contract: AF 33(616)-7075, Proj. 7367, Task 736701. 9 refs. A63-279.

Product yields are reported for  $Co^{60}$ -gamma radiolysis of dilute benzene solutions of tetraphenyls of Si, Ge, Sn and Pb and triphenyls of As and Bi. The latter four compounds undergo a concentration-dependent, sensitized decomposition best explained in terms of energy transfer from excited benzene to organometallic.  $G(H_2)$  and  $G(C_2H_2)$  for benzene are unaffected by any of the solutes indicating that these two products are formed from a state or states of benzene other than the state(s) transferring energy to the Organometallic. The ability of solutes to undergo radiation-sensitized decomposition is compared with ability to quench luminescence of scintillators in benzene solutions. Qualitative agreement is found in that good quenchers undergo sensitized decomposition while poor quenchers ( $Si\phi_4$  and  $Ge\phi_4$ ) do not. (Author)

2-486 A THEORETICAL INVESTIGATION OF CRIMP INTERCHANGE IN A WOVEN FABRIC UNDER BIAXIAL STRESS. Peter G. Popper. Period covered: Apr.-Dec. 1961. Aeronautical Systems Div., Wright-Patterson AFB, Ohio, Final Report, ASD-TDR-62-457, Aug. 1962. 56p. illus. Proj. 7320, Task 732002. 4 refs. A62-12538.

This report describes the theoretical behavior of a woven fabric which is subjected to biaxial stresses. The stress-strain equations are derived for an idealized plain-weave fabric which extends by means of crimp interchange. To obtain solutions to these equations it was necessary to use an iterative procedure on a digital computer. The results have been presented in several ways and may be used in the design of such items as pressurized structures.



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A number of sample solutions using the computer results are given. The rigidity of pressurized fabric structures has been found to be of great significance in present day engineering. In a pressure suit it should be very low and in other uses such as inflatable planes, reentry gliders, and space antennas it should be high. The basic property of a fabric which will determine the overall rigidity is the resistance of a biaxially stressed fabric to deform. Thus the results found in this report can be used. They will be a means for either predicting the performance of a given fabric or for determining which fabric would be most suitable for a particular application.

SECTION B - METALLURGY

- 2-487 CREEP-RUPTURE PROPERTIES OF SIX ELEVATED TEMPERATURE ALLOYS. John G. McBride, Bradford Mulhern, and Robert Widmer. Period covered: Feb. 1960-Feb. 1962. New England Materials Laboratory, Inc., Medford, Mass., Final Report, WADD-TR-61-199. Aug. 1962. 66p. illus. Contract: AF 33(616)-6200, Proj. 7381, Task 738103. A62-11153.

Room temperature tensile properties, short time elevated temperature properties, and elevated temperature creep-rupture properties were determined for six widely used elevated temperature alloys. Representative commercial lots of Udimet 700 (Bar), R-235 (Bar), GMR-235 (Cast Bar), René 41 (Sheet), R-235 (Sheet), and Nicrotung (Cast Bar) were tested at each of three typical application temperatures. Tabulated tensile and creep-rupture data, stress versus rupture-life curves, creep versus time curves, and stress versus time to 0.2 and 1.0% total creep curves are presented. (Author)

- 2-488 THE EFFECT OF SIZE AND STRESS HISTORY ON FATIGUE CRACK INITIATION AND PROPAGATION. Waloddi Weibull. Period covered: Sept. 1960-Sept. 1961. Aeronautical Systems Div., Wright-Patterson AFB, Ohio, Summary Report, ASD-TDR-62-785. Aug. 1962. 23p. illus. Contract: AF 61(052)-522, Proj. 7351, Task 735106. 8 refs. A62-11127.

This investigation deals with the effect of size and preloading on the duration  $N_i$  of the crack initiation period, as well as the crack propagation period. Geometrically similar sheet specimens of two aluminum alloys were used. Each size exhibited its individual S- $N_i$  curve. A static preload increased the  $N_i$  from 11 to 205 kc. Equations relating crack length to number of cycles are derived for constant stress cycle and constant load cycle. The formulas are verified by tests for various combinations of material, size and stress amplitude. For constant stress the rate of crack growth was found, independently of crack length, to be constant after a certain transition period which is dependent on the duration of the preceding initiation period. For constant load cycle the propagation period starts with a transition period followed by one or more stable propagation periods, their number depending on load magnitude. Failure analysis showed these periods corresponding to different fatigue mechanisms. It is concluded that total fatigue life cannot be predicted without considering separately the parts of which it is composed. (Author)

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- ( 2-489 INVESTIGATION OF THIN SHEETS OF HIGH-QUALITY, SINGLE-CRYSTAL SILICON. F. T. Fitch. Final Technical Summary Report, for period 1 Sept. 1959-31 Aug. 1960. W. R. Grace and Co., Clarksville, Maryland, Rept. no. 3. 10 Sept. 1960. 30p. Contract: DA-36-039-SC-85242, ARPA order no. 80-59. A62-12206.

The properties of the molten silicon-lead system and possible techniques to pull a thin, single-crystal silicon sheet were studied in a small high temperature furnace of special design. Lead vapor difficulties permitted only short exploratory melts which were sufficient to establish the limitations in this approach. Liquid silicon and lead were mutually soluble to about 3 atom per cent close to the silicon melting point. Silicon crystallized on cooling in an uncontrolled manner from the lead phase primarily as polycrystalline platelets. Individual crystals occurred as flat rhomboids of 0.02 to 0.05 mm thickness, up to 2- mm length, with 60 and 120° angles. The dissolved silicon, in pulling attempts, crystallized from the lead phase at the slightly lower temperatures surrounding the seed. This crystallization was extensive enough at times to interfere mechanically with the pulling. It disturbed the crystallization of the sheet from the molten lens and would prevent this method from yielding the thin sheet in the form of a single crystal. The high surface tension of silicon resulted in a thick molten lens unsuited for crystal pulling due to a tendency to part, to have considerable motion, and to make an unstable fluctuating liquid-solid contact. Maintaining the lens under tension between the seed and the contact over much of its circumference with a wettable material (SiC) provided a thin stable liquid contact from which silicon sheets could be pulled. With further improvements this method might be developed to yield thin silicon sheets (polycrystalline) probably in the range of 1.0 to 0.1 mm thickness.

- 2-490 ORDERING IN OXIDE SOLID SOLUTIONS. H. H. Wilson. Period covered: May 1961-Apr. 1962. Clemson College, Clemson, South Carolina, Interim Report, ASD-TR-61-92, Part II. Oct. 1962. 10p. illus. Contract: AF 33(616)-6870, Proj. 7350, Task 735001. 5 refs. A61-10561, pt. 2.

( ) A study was made of solid solutions of magnesium oxide with manganese, iron and cobalt oxides to determine the effect of extended heat treatment and of controlled furnace atmospheres on the formation of superlattices. Heat treatments involving temperatures up to 1350°C. and times up to 600 hours were used. Furnace atmospheres were controlled so as to be either neutral, slightly oxidizing, or slightly reducing with respect to the divalent metallic ions. Indications of ordering were found in those compositions that were heated in reducing atmospheres. A broad diffraction peak was found at 6.4 Å which is three times the (002) spacing of the unordered lattices. (Author)

- 2-491      STEELS FOR LARGE SOLID-PROPELLANT ROCKET-MOTOR CASES. J. E. Campbell. Battelle Memorial Institute, Columbus, Defense Metals Information Center, Rept. no. 178. 20 Nov. 1962. 32p. illus. Contract: AF 33(616)-7747, Proj. 2(8-8975. 35 refs. A63-59.

The major high-strength steel alloys used for large solid propellant rocket-motor cases are discussed in this report. Of particular interest for current rocket-case applications are AISI4340, AMS6434 (modified), Ladish D-6ac, and H-11 hot-work tool steel. The composition of these and other steel alloys (incl. high-silicon, silicon-cobalt, and high-nickel maraging steels) is presented. The mechanical properties of high-strength steels are briefly discussed and individual properties (yield strength, tensile strength, elongation, hardness, etc.) for various tempering temperatures are given in a table form. Finally, a review of pressure-vessel tests is given, and selected data from burst tests on subscale motor cases and pressure vessels, as well as the chemical analyses and processing data for various steels alloy are compiled in a table form.

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2. Alper, R. H., "Development of Ultra High Strength Rocket Motor Cases by Cryogenic Stretch Forming", Final Report of ARDE-Portland, Inc., for United States Army on Contract No. DA-30-069-ORD-3099 (February 15, 1962).
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2-491 (Continued)

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10. Goodman, J. W., "Pressure Vessel Design Criteria", Final Report No. TR 61-9 of Space Technology Laboratories, Inc., Los Angeles, California, for United States Air Force on Contract No. AF 04(647)-619 (December 31, 1960).
11. Ginsburgh, A. S., "Pressure Vessel and Mechanical Test Evaluation of Ladish D-6ac Steel", Aerojet-General Corporation, Sacramento, California, Technical Note 60-3 for United States Air Force on Contract No. AF 33(600)-36610 (November, 1960).
12. Sigrist, E. L., and Meissner, F. H., "Investigation of the Structural Integrity of 37.5-in. Diameter Subscale Minuteman Chamber of Ladish D-6ac Steel", Aerojet-General Corporation, Sacramento, California, to United States Air Force on Contract No. AF 33(600)-36610 and Supplemental Agreement No. 14, ASTIA AD 263469 (September 20, 1961).

2-492 THERMAL EXPANSION OF ALUMINUM OXIDE ( $Al_2O_3$ ) AND BERYLLIUM OXIDE ( $BeO$ ). Gary L. Denman and Daniel L. Smith. Aeronautical Systems Div., Wright-Patterson AFB, Ohio, Directorate of Materials and Processes, ASRCE-TM-62-18. Oct. 1962. 2p. Proj. 7381, Task 738103. A62-11756.

The thermal expansion of a series of Aluminum Oxide and Beryllium Oxide is reported. The purity of the materials range from 85 percent to 99.5 percent. A brief discussion of the dilatometer used for the tests is also included. (Author)

2-493 THERMOPHYSICAL PROPERTIES OF RUBIDIUM. F. Tepper, A. Murchison, J. S. Zelenak, and F. Roehlich. MSA Research Corp., Callery, Penna., Final Report, ASD-TDR-63-133. Feb. 1963. 70p. illus. Contract: AF 33(657)-7659, Proj. 3145, Task 314507. 120 refs. A63-4280.

A program was undertaken at MSAR to determine the thermophysical properties of rubidium and cesium. Phase I includes the following property measurements for rubidium between 500° and 2000°F: (1) vapor pressure, (2) density of liquid, (3) specific heat of liquid, and (4) PVT of the vapor. A considerable part of the effort associated with the program has been

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in rubidium and cesium is necessary to establish the sensitivity and precision necessary. The aim of oxygen analysis in this program was to arrive at the state-of-the-art for Rb comparable to that which now exists for Na. The two methods considered were (1) amalgamation and (2) the butyl bromide method. Several variations in the amalgamation method were tried. Average deviations ranged from 1.5 to 17 ppm. The butyl bromide method was not attempted during this report period. All equipment used in the physical properties determinations was fabricated from a ductile cobalt base alloy, Haynes No. 25. Durations of exposures to Rb at temperatures in excess of 1800°F were limited due to the possibility of decarburization of the Haynes alloy by the zirconium getter employed in the experiments. All samples used in the determinations were distilled to high purity and analyzed for Cs, K, Na, N and C. In all cases the purity of the samples are reported. The vapor pressure apparatus consisted of a boiler and an air condenser which was attached to a manifold connecting a source of pure argon and appropriate pressure measuring devices. The argon pressure was set at the desired value, the power to the furnace was adjusted until boiling occurred at the desired rate; after 5 minutes or more of equilibrium the temperature of the boiler thermocouple and the pressure of the argon in the manifold were recorded. Data were fitted to three equations, the directed towards the development of techniques for analysis of impurities in the rubidium employed for physical property determinations. Foreign metallic impurities in Rb were determined using a Model DU-2 Beckman Flame Spectrophotometer. Due to flame interference in the analysis of trace cesium and potassium x-ray fluorescent techniques were employed to verify the flame spectrophotometric values. Nitrogen, as nitride, was determined via a modified Kjeldahl method. A method for the analysis of carbon in sodium has been developed. Further analytical work for carbon recommended equation being:

$$\log_{10} P = \frac{-7,110.53}{T} - 0.140579 \log_{10} T + 4.5060749$$

(P in atm. abs. and T in °R).

The dilatometer method was chosen for the density determinations. X-ray photos were used to determine the height of the meniscus in the Haynes Alloy tubing. The apparatus was charged with a known quantity of Rb and the temperature raised so that the meniscus was located in the tubing. It was necessary to apply an argon pressure somewhat in excess of the boiling point at the temperature of interest in order to suppress boiling. Sixty data points were obtained over the temperature range 150°F to 2000°F. All data were analyzed for 8 functional forms. The following equation is recommended because it is the simplest expression achieving a standard deviation of 0.0035 g/cc, which is equivalent to a precision of about 0.3%.

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$$\rho = 1.55643 - 0.265111Z - \frac{0.00626779}{Z}$$

(where  $Z = t/1000$ ;  $\rho = \text{g/cc}$ ;  $t = \text{degrees F}$ ).

The specific heat of liquid Rb was determined in a gold plated, copper calorimeter; the drop method was used. Using the experimental data the following equation was fitted by the least squares method for the range 500 to 1400°K:

$$H_T^O - H_{298}^O \text{ (cal/mole)} = 7.53T - 1624$$

The remainder of this report is concerned with: plans for determination of the viscosity of Rb; a discussion of the results of that portion of the literature survey concerned with thermal conductivity of liquid Rb; proposed methods for the determination of vapor species (to be used only if PVT data suggests non-ideality); methods of determining the viscosity, specific heat, and thermal conductivity of the vapor, as reported in the literature; determination of latent heat of vaporization, as reported in the literature; and discussion of the construction of a Mollier diagram. An extensive literature survey was made as background for this work; discussion of data from various references is interspersed throughout the report in the appropriate sections and a complete citation bibliography appears at the end of the report. Recent reports from this bibliography not published in the open literature are cited in the accompanying bibliography.

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7. Ewing, Stone and Miller, NRL Memo Report 1069, July, 1960.
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9. Battelle Memorial Institute, Quarterly Reports 1-8, NAS 5-584 (1961-62).
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SECTION C - REFRACTORY MATERIALS

- 2-494      COMPARISON OF HIGH ENERGY RATE (DYNAPAK)  
AND CONVENTIONAL EXTRUSION OF REFRACTORY METALS.  
Dirk G. Rahenold. Period covered: Mar. 1961-Mar. 1962.  
Westinghouse Electric Corp., Blairsville, Penna., Final  
Report, ASD-TDR-62-506. Sept. 1962. 90p. illus.  
Contract: AF 33(616)-7842, Proj. 7381, Task 73811, 6 refs.  
A62-11208.

A comparison was made of the surface quality, dimensions, chemistry, hardness, tensile properties, and recrystallization behavior of extrusions produced on a Model 1810 Dynapak high-velocity machine and on a 700-ton Loewy high speed extrusion press. Three temperatures were established which represented hot work, cold work, and a combination of hot and cold work, by making preliminary extrusions on the Dynapak machine. Arc cast billets, with a nominal diameter of three inches, of two refractory alloys, a Mo-25W-0.1Zr alloy and a W-0.6Cb alloy, were then extruded at a constant 4:1 reduction ratio from the same three temperatures on both machines. The results of this work indicate that equally good surfaces can be obtained from either process when proper lubrication and die preparation techniques are used; a lower recrystallization temperature is obtained in material cold worked on the Dynapak. The latter fact indicates that high-velocity-extruded metals retain a higher degree of internal stress than conventionally-extruded metals. (Author)

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3. Houck, J. A., "Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys", DMIC Report 140, Battelle Memorial Institute, Columbus, Ohio - November 30, 1960.
4. McKinsey, C. R., et al, "Investigation of Tungsten - Tantalum - Columbium - Base Alloys", WADD Technical Report 61-3 - July, 1961.

- 2-495      DEVELOPMENT OF IMPROVED VANADIUM-BASE ALLOYS  
FOR ELEVATED-TEMPERATURE USE. V. C. Petersen  
and H. B. Bomberger. Period covered: 1 May 1960-  
31 Apr. 1962. Crucible Steel Company of America,  
Pittsburgh, Final Report, ASD-TDR-62-667. 66p. illus.  
Contract: AF 33(616)-7288, Proj. 7351, Task 735103.  
A62-12501.

Work was done to develop vanadium-base alloys having improved mechanical properties at elevated temperatures. The screening



( ) 2-495 (Continued)

criteria included density-corrected hot hardness at 1800°F as well as forgeability performance at 2300°F. The hot-hardness apparatus designed for the work permits loading up to 14 specimens at one time and testing up to 1800°F in vacuum. The validity of hot hardness as a hot strength parameter was established by a correlation with hot-strength data. In the exploratory work, 174 binary and multi-addition alloys were levitation-melted in 10-gram charges. Based on these studies of the microstructures, forgeability, and hot hardness of these alloys, 14 compositions were selected as most promising and were scaled up to larger melts. Screening data (rollability, hot hardness, and hot tensile properties) on the larger melts showed three compositions to be superior: V-20Cb-5Ti, V-25Mo-2.5Hf, and V-35Cr-1Zr. These alloys demonstrated better forgeability and superior 2000°F tensile strength than the well-known V-20Cb-5Ti alloy. Iron and tin were also found to be promising alloying elements for further study. (Author)

2-496 EFFECT OF COMPRESSIVE LOADS ON STRUCTURAL FATIGUE AT ELEVATED TEMPERATURE.  
Laszlo Berke. Period covered: 15 June 1961-14 June 1962. Douglas Aircraft Co., Inc., Long Beach, Calif., Final Report, ASD-TDR-62-448. Oct. 1962. 159p. illus. Contract: AF 33(616)-8103, Proj. 1467, Task 146704. 35 refs. A63-23.

The effects of compressive loads on structural fatigue at elevated temperatures are investigated using plain, notched, and welded titanium 8Al-1Mo-1V, and PH 15-7Mo stainless steel coupon specimens. Specimens are subjected to Mach 3 spectrum test environment, including compressive loads. Fatigue life predictions are compared with spectrum test results. The influence of prior stress-strain history on subsequent life is considered. Prediction methods are extended to include the compression range, and results are compared with spectrum tests. Plastic stress distribution of notched specimens is determined analytically and experimentally. A variety of individual variable fatigue tests are performed at temperatures up to 900°F. (Author)

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10. Liu, H. W. and Corten, H. T., "Fatigue Damage Under Varying Stress Amplitudes", NASA TN D 647, November 1960.

2-497 INVESTIGATION OF FACTORS RELATED TO AN UNKNOWN PHASE IN B120 VCA TITANIUM ALLOY. David W. Levinson. Period covered: 15 Apr. 1961-15 Apr. 1962. Armour Research Foundation, Chicago. Final Report, ARF 2222-12; ASD-TDR-62-534. Oct. 1962. 62p. illus. Contract: AF 33(616)-8149, Proj. 7351, Task 735105. 9 refs. A62-12430.

A study was made of the needle-like precipitate which had been observed to occur in B120 VCA as a result of welding or of solution treating at temperatures above 1100°C. The phase was found to be the alpha phase, stabilized by oxygen. Under conditions of strict oxygen exclusion the alpha needles do not appear. The embrittlement of material aged after either welding or overheating during solution treatment was found to be unaffected by the alpha needles. Embrittlement occurred whether or not needles were present in the microstructure. Some evidence is presented which implies that omega phase precipitation may produce the embrittlement. (Author)

- 2-498 MACHINING OF REFRACTORY MATERIALS. N. Zlatin, M. Field, and J. Gould. Period covered: 1 May-31 July 1962. Metcut Research Associates Inc., Cincinnati, ASD-TR-7-532a (VII). Aug. 1962. 136p. illus. Contract: AF 33(600)-42349, Proj. 7-532a. A61-5079.

Machining studies were performed on pressed and sintered, forged and resintered, and arc cast unalloyed tungsten; D-31 columbium, 90Ta-10W alloy; silica reinforced phenolic resin; solid zirconium oxide; and zirconium and aluminum oxide coatings. The investigation consisted of face milling, end milling, drilling and tapping studies on tungsten and D-31 columbium; turning, face milling, drilling and tapping on silica reinforced phenolic resin; grinding of solid and flame sprayed zirconium and aluminum oxide coatings; and turning, face milling, end milling, drilling, reaming, tapping and grinding on the 90Ta-10W alloy. (Author)

- 2-499 PYROLYTIC GRAPHITE AND RELATED REFRACTORY MATERIALS: AN ANNOTATED BIBLIOGRAPHY. Jack B. Goldmann. Lockheed Missiles and Space Co., Div. of Lockheed Aircraft Corp., Sunnyvale, Calif., Special Bibliography, SB-62-27. Sept. 1962. 57p. A63-3986.

A survey of printed sources which refer to pyrolytic graphite and related refractory materials was made for the period July 1961 to June 1962. This annotated bibliography includes references to pyrolytic boride, pyrolytic carbide and pyrolytic carbon, as well as pyrographite. Other areas for investigation were tantalum boride; silicon, tantalum, titanium and zirconium carbide; and boron and titanium nitride. (Author)

- 2-500 REFRACTORY METAL CONSTITUTION DIAGRAMS. E. J. Rapperport, M. F. Smith, J. Wulff, J. Brophy, N. J. Grant, B. C. Giessen, A. Taylor, and N. Doyle. Period covered: Apr. 1960-Dec. 1961. Nuclear Metals, Inc., Concord, Mass., in conjunction with Massachusetts Inst. of Tech. and Westinghouse Research Labs., Final report, WADD TR 60-132, Pt. II. Sept. 1962. 185p. illus. Contract: AF 33(616)-7157, Proj. 7351, Task 735101. 43 refs. A62-11056, pt. 2.

Data on six binary constitution diagrams and two ternary constitution diagrams of some of the refractory metals are presented. The binary diagrams include Mo-Os, Ta-Ir, Ta-Rh, Ta-Zr, W-Ir, and W-Rh; the ternaries are Mo-Hf-Re and Ta-W-Zr. Care was taken to obtain reliable diagrams. In particular the purity of the constituents (99.9 percent plus) was protected at all times, and the temperatures were measured to an accuracy of  $\pm 20^{\circ}\text{C}$ . (Author)

- 2-501 THERMAL CONDUCTIVITY OF ANISOTROPIC SOLIDS AT HIGH TEMPERATURES. Part I. The Thermal Conductivity of Molded and Pyrolytic Graphites. Michael Hoch and Joseph Vardi. Period covered: Feb. 1961-Feb. 1962. University of Cincinnati, Interim Report, ASD-TDR-62-608, Part I. Nov. 1962. 19p. illus. Contract: AF 33(616)-7123, Proj. 7364, Task 73652. 12 refs. A63-1166, pt. 1.

A method has been developed for the determination of the thermal conductivities of anisotropic solids under conditions of two-dimensional, steady-state heat conduction in a cylinder of finite length heated in vacuum by high frequency induction and radiating heat to the surroundings. The method has been used to determine the radial thermal conductivity,  $k_r$ , and the axial thermal conductivity,  $k_z$ , of molded ZT type and pyrolytic graphite in the temperature range 1200-2200°K. For ZT type graphite  $k_z/k_r = -0.10116 + 2.00191 \times 10^{-4} \times T$  (1260°K < T < 2199°K); for pyrolytic graphite,  $k_z/k_r = 0.0376$  at 1817°K.

(Author)

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4. Rasor, N. S. and McClelland, J. D., "Thermal Properties of Materials," WADC Technical Report 56-40, Part I (1957).

- 2-502 THE THERMODYNAMICS OF THE GRAPHITE-CARBON VAPOR SYSTEM. F. J. Krieger, RAND Corp., Santa Monica, Calif., RM-3326-PR. Sept. 1962. 31p. illus. Contract: AF 49(638)-700. 3 refs. A63-1476.

The purpose of this study is the thermodynamic investigation of graphite over a range of temperatures up to 6000°K and pressures up to  $10^3$  atmospheres. Two sets of equilibrium composition equations were used--one representing a pure gas phase, the other a heterogeneous system of gas and solid carbon. The heterogeneous chemical system is unique in that, although it involves two phases and a variety of chemical species, it comprises only one chemical element. The mathematical solution of the system of equations representing the heterogeneous chemical system, therefore, required a physical constraint on the volume associated with the conditions of sublimation of graphite. The results of the computational program are presented in both tabular and graphic form. The latter is a conventional Mollier diagram in which specific enthalpy is plotted against specific entropy, with cross plots of temperature, pressure, and molecular weight. (Author)

## SECTION D - POLYMERIC AND COMPOSITE MATERIALS

- 2-503 ABLATIVE ELASTOMERIC INSULATION MATERIALS.  
 Roger E. Headrick. Period covered: Mar. 1961-  
 Jan. 1962. Aeronautical Systems Div., Wright-Patterson  
AFB, Ohio, Directorate of Materials and Processes,  
Final Report, ASD-TDR-62-400. Aug. 1962. 29p. illus.  
 Proj. 7340, Task 734005. 15 refs. A62-11128.

This is a report of a preliminary investigation of representative vulcanizates of nearly all types of elastomeric polymers as ablative insulations from oxy-acetylene torch and the arc-plasma jet evaluations. In these evaluations acrylonitrile/butadiene copolymer (NBR) based compounds, which are now the most widely used in insulation compounds, were rated only fair among the materials investigated. The silicones, the polysulfides, and vinyl pyridine/acrylonitrile vulcanizates exhibited appreciably higher thermal protection than did NBR vulcanizates. Also reported are the results of a literature survey and a detailed discussion of the evaluation procedures and equipment. (Author)

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8. Economos, C., Results of Ablation Tests on Several Plastic Models in a Hypersonic Wind Tunnel, WADD-TN-60-273.
9. Farmer, R.W., Ablative Behavior of Plastics in Subsonic and Supersonic Hyperthermal Flow, WADC-TR-60-648.
10. Epstein, G., Elastomeric Insulation Materials for Rocket Motors, Aerojet-General Corporation Report SP-TP-30a.

- 2-504      **HIGH TEMPERATURE COMPOSITE STRUCTURE.**  
R. M. Davis and C. Milewski. Martin Co., Baltimore,  
Final Report, ASD-TDR-62-418. Sept. 1962. 253p. illus.  
Contract: AF 33(616)-7497, Proj. 1368, Task 136804.  
22 refs.      A63-2495.

Two reentry heat shield systems intended for efficient operation with surface temperatures in the range of 3000° to 4000°F when adapted to spherical nose cap shapes were designed, developed, fabricated, tested and evaluated. The heat shields were of the radiative type, utilizing a foamed aluminum oxide material in the structural insulation design concept. Dense facings and resin impregnation were used to alter the basic foam, with the latter proving the better modification as shown by simulated reentry tests in a large hot gas facility. Effects of various combinations of plasma jet enthalpy and heating rates on resin-impregnated ceramic foams were compared. These more closely simulated reentry conditions for ablative (and semi-ablative) type materials.  
(Author)

- 2-505      **IMPREGNANTS FOR EXPANDABLE RIGIDIZABLE AEROSPACE STRUCTURES.** Adolf Damusis, Harry Wissman, and Alexander Sanger. Quarterly Progress Report no. 2, 1 Aug.-31 Oct. 1962. Wyandotte Chemicals Corp., Wyandotte, Michigan. No rept. no. 15 Nov. 1962. 32p. Contract: AF 33(657)-9174, Proj. 7340, Task 734005. A62-11704.

Investigations on the epoxy and urethane resins as candidate resins for rigidizing aerospace structures was continued. The prepolymers investigated were derived from polyoxypropylene diols, triols and tetrols; two new polyols were added. Major effort was devoted to (1) the characterization of the select prepolymer systems, (2) investigation of physical properties of the urethane resin-glass fabric systems and (3) the initiation of investigation of inner barrier materials for moisture cured urethane systems. Included have been temperature-viscosity studies, measurement of curing rates and the determination of flexural strength of laminates at intermediate stages of curing.

- 2-506      **INVESTIGATION OF THE THERMAL BEHAVIOR OF GRAPHITE AND CARBON-BASED FIBROUS MATERIALS.** Frederic S. Dawn and Jack H. Ross. Period covered: Dec. 1960-Aug. 1961. Aeronautical Systems Div., Wright-Patterson AFB, Ohio, Final Report, ASD-TDR-62-782. Oct. 1962. 34p. illus. Proj. 7320, Task 732002. A63-602.

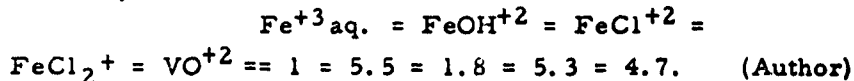
The elevated temperature properties of graphitized and carbonized polymeric fibrous materials were investigated as part of a research

2-506 (Continued)

program on high temperature fibrous materials for use in parachutes and other decelerators, and in expandable structures. Experimental quantities of woven materials were evaluated after they were exposed to various temperatures for specific periods. One of these materials was partially graphitic (as shown by some order in X-Ray diffraction), the other two were amorphous carbon (no pyrolysis of polymers while in fabric form). Characteristics investigated as related to temperature and time at temperature were: breaking load to rupture, breaking elongation, energy absorption, and breaking strength after repeated stressing. The graphitized fibrous material was superior in tenacity initially and at 600°F, to the carbonized materials investigated. Also, these materials were superior to nylon at temperatures above 350°F. Future investigations will be conducted to characterize the behavior of the carbonized and graphitized fibrous materials in the range of 600° to 2000°F.  
(Author)

2-507 KINETIC STUDY OF ION-SENSITISED TERMINATIONS OF RADICAL POLYMERISATION. E. A. S. Cavell.  
Period covered: 1 July 1961-30 June 1962. University of Southampton, Southampton, England, ASD-TR-61-561.  
Part II. Oct. 1962. 13p. Contract: AF 61(052)-376,  
Proj. 7342, Task 734203. 9 refs. A62-5202, pt. 2.

The investigation of the azo initiated aqueous polymerisation of acrylamide has been extended to consider termination of the growing radical chains by ferric sulfate, ferric chloride and a vanadyl perchlorate. The predicted effects due to radical termination by transition metal ions was found. The relative efficiencies of various species in terminating the acrylamide radical was found to be:



#### References

1. E. A. S. Cavell, Annual Summary Report No. 1 Contract AF 61(052)-376 July 1961.
2. E. A. S. Cavell, Quarterly Progress Report No. 5 Contract AF 61(052)-376 January 1962

**Polymeric and Composite**

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- 2-508      RESEARCH ON ABSORBING INFRARED RAYS WITH  
PLASTICS AND ATTENUATING INFRARED RAYS WITH  
COATINGS. Peter V. Susi and Haig C. Conoian.  
Period covered: 1 Apr. 1961-30 Apr. 1962. American  
Cyanamid Co., Bound Brook, N. J., Final Report,  
AMRL-TDR-62-92. Aug. 1962. 94p. illus. Contract:  
AF 33(616)-8056, Proj. 6301, Task 630103. 32 refs.  
A62-12215.

The following types of compounds were prepared: (1) Substituted Phenyl-fluorenol Salts; (2) Triarylaminiun Free Radical Salts; (3) Polymethines; (4) Metal Complexes; and (5) Phenothiazine Derivative. With the specific objective of developing a plastic or coating composition having strong near-infrared attenuation and high visible transmittance, a number of organic compounds were prepared and along with many compounds from chemical files were examined spectrophotometrically in solution. Those with near-infrared absorption were incorporated into plastics by one or more of the following methods: solution casting, milling and molding, monomer casting, burnishing, or dyeing. Absorption properties were then measured and light stabilities were determined after accelerated light exposure tests.



## SECTION E - ELECTRIC, ELECTRONIC, AND MAGNETIC MATERIALS

- 2-509 FAST NEUTRON DAMAGE TO SELECTED SEMICONDUCTOR DEVICES. Harold B. Almond. Boeing Airplane Co., Seattle, Rept. no. D2-7427. Oct. 1960. 294p. illus. No contract no. 3 refs. A63-1402.

Seventeen types of transistor devices were investigated for permanent damage produced by fast neutron irradiation. All tests were performed at the Godiva II prompt critical facility, Los Alamos, New Mexico. The types of transistors tested ranged from a 15 ampere silicon power transistor to silicon and germanium high frequency tetrodes. Two special types, a C-35 silicon controlled rectifier and a 2N491 silicon unijunction were tested. Neutron dosimetry was performed using sulfur threshold dosimeters with the results being converted to equivalent plutonium dosimeter neutrons. Neutron dosage ranged from  $1.76 \times 10^{11}$  nvt to  $7 \times 10^{13}$  nvt. The transistor data is presented in terms of  $\beta$  (small signal) versus  $I_e$ ,  $\beta$  (large signal) versus  $I_e$ ,  $I_{co}$  versus neutrons/cm<sup>2</sup>, and  $I_{co}$  versus temperature. The basic photographic data is presented for one transistor of each type tested for the benefit of those wishing to obtain  $\beta$  values at different collector voltages. (Author)

- 2-510 RESEARCH ON SPONTANEOUS MAGNETIZATION IN SOLID BODIES. Angus Neaves. Franklin Institute Labs., Philadelphia, ASD-TDR-62-375. Apr. 1962. 31p. illus. Contract: AF 33(616)-7499, Proj. 7371, Task 737103. 10 refs. A62-12536.

A series of very fine particle ferrites ranging in size from 18Å to 200Å<sup>0</sup> has been subjected to magnetic resonance investigation. These particles show an increasing shift in resonance field with decreasing particle size. The behaviour of this shift with decreasing temperature is more complicated. These and other results are discussed on the basis of two ferromagnetic resonance equations. The first of these equations removes the restrictions generally imposed in the derivation of the equation of ferromagnetic resonance. This equation should be useful in the description of resonance in macroscopic single crystal ferrites. The second equation takes account of the super-paramagnetic nature of the particles and predicts results qualitatively in agreement with those observed. Some work on nickel oxide particles exhibiting weak ferromagnetic and superparamagnetic effects is described. (Author)

- 2-511      THEORY OF RELAXATION PROCESSES IN FERROMAGNETIC  
             INSULATORS. M. Sparks. Stanford University, Stanford,  
             Calif., Rept. no. 932; AFCRL-62-566; AFOSR-2999.  
             July 1962. 27p. Contract: AF 19(628)-342, Proj. 4600;  
             AF 49(638)-415, Proj. 47501. 61 refs. A62-8905.

This report presents a simplified physical description of ferromagnetic relaxation, summarizes the theories of the important relaxation processes in yttrium iron garnet (YIG), discusses the transition probability method of ferromagnetic relaxation frequency calculations and the methods of measuring the frequencies. Magnons, or quantized spin waves, are discussed from a physical point of view, and the Holstein-Primakoff transformations to magnon variables are discussed.

## SECTION F - FLUIDS AND LUBRICANTS

- 2-512 FRICTION AND WEAR AT ELEVATED TEMPERATURES. Ernest Rabinowicz and Masaya Imai. Massachusetts Inst. of Tech., Cambridge, Final Report, WADC TR 59-603, Pt. III. July 1962. 49p. illus. Contract: AF 33(616)-7648, Proj. 7342, Task 734204. 8 refs. A61-10480, pt. 3.

The possibilities of low melting metals as high temperature liquid lubricants have been investigated. Since the metals exist as solids at room temperature and the melting temperature must be surmounted when sliding devices are operated over a wide temperature range, the "friction during melting phenomenon" has been studied intensively. In order to check the effects of oxidation, friction tests have been carried out both in air and in inert gas atmosphere and the results are compared with those obtained with the metal oxides. Some low melting metals gave a friction peak at the melting point, in the same way as do glass-like lubricants. Other metals which did not give the peak have been affected by oxidation. Exceptions to this rule are found with tin and cadmium in argon. Although they were not oxidized, they did not give any friction peak. The friction of molybdenum alloys has been studied at elevated temperatures. The results have shown the marked effects of molybdenum oxide formed on the sliding surface. It was found that molybdenum oxide and boric oxide vapor can contaminate the friction apparatus and effect subsequent friction tests. Pyrolytic graphite and pyrolytic boron nitride have been tested both at high temperatures and at room temperature, and the results are compared with those obtained with ordinary graphite and boron nitride. No appreciable difference was found between the pyrolytic specimens and ordinary specimens. Graphite gave low friction at high temperatures and showed substantial promise for the use at high temperatures, while boron nitride gave poor frictional performance at high temperatures.

- 2-513 INORGANIC THICKENED GREASES. John B. Christian. Period covered: May 1961-May 1962. Aeronautical Systems Div., Wright-Patterson AFB, Ohio, Directorate of Materials & Processes, Final Report, ASD-TDR-62-815. Sept. 1962. 10p. illus. Proj. 3044, Task 304403. A62-11748.

Experimental inorganic thickened greases were synthesized and characterized using standard and specialized techniques. The greases were formulated from high melting inorganic solids, and polyphenyl ethers, high phenyl content silicones, inhibited silicones, and fluoro-silicones. The thickening ability of several inorganic solids was determined. Many of the grease formulations show promise for such applications as anti-friction bearing lubricants, high temperature pneumatic greases, and lubricants for use in applications of sliding and rolling friction under heavy load conditions. (Author)

SECTION G - FABRICATION TECHNIQUES AND PROCESSES

- 2-514 DESIGN, FABRICATION, AND HYDROTESTING OF A 120-INCH DIAMETER PRESSURE VESSEL USING 18 PERCENT NI MARAGING STEEL. J. Scott Coverdale. Research Contract Status Report No. 2, 16 Dec. - 15 Jan. 1963. Lockheed Propulsion Co., Redlands, Calif., Rept. no. 609-P-2. 29 Jan. 1963. 22p. illus. Contract: AF 04(611)-8525. A63-1715.

Material and fabrication research findings to date are presented. The test specimens from U. S. Steel are not yet prepared so material testing of maraging steel from other sources has continued. In coordination with Naval Research Laboratories, results were correlated of machine notch specimen fracture toughness values from tests with natural crack tests. All forgings have been completed and summaries presented. Fabrication development work continues of plasma arc burning for weld preparation, and data to date is given. Results of tensile tests of bolt material are given. A revised program planning and status chart is presented. (Author)

- 2-515 INVESTIGATION OF SINTERABLE MgO POWDER AND CERAMICS MADE FROM THEM. M. J. Snyder, A. Rudnick, W. H. Duckworth and C. Hyde. Period covered: 1 Jan. 1961-31 May 1962. Battelle Memorial Institute, Columbus, Final Report, ASD-TDR-62-700. Oct. 1962. 48p. illus. Contract: AF 33(616)-7733, Proj. 7350, Task 735001. 27 refs. A63-55.

The fabrication of dense reproducible specimens suitable for strength measurements and having controlled microstructural differences are attempted. A sinterable high-purity magnesia powder, developed in an earlier phase of the program, was used. Procedures used earlier to produce small, rather crude specimens, could not be applied directly to controlled production of the quantity of large specimens needed. The sintered densities of the larger specimens were lower, and the variability from one lot to the next was greater. The major source of variability appeared to reside in the isostatic pressing operation. This unexpected sensitivity to forming conditions other than pressure suggests the need for further research on processing effects in ceramics made from sinterable powders. A portion of the effort was devoted to analysis and development of the diametral-compression test wherein short cylinders are broken by applying a load across a diameter. Procedures were established for measuring a tensile strength by this method. (Author)

2-515 (Continued)

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2. Johnson, J. E., Smalley, A. K., and Duckworth, W. H., "Investigation of Sinterable Powders and Properties of Beryllia Ceramics", WADD TR-60-108, April, 1960.
3. Hyde, C., and Duckworth, W. H., "Investigation of Sinterable Oxide Powders and Ceramics Made From Them", WADD Technical Report 61-262, June, 1961.

2-516 JOINING OF REFRACTORY METALS BY BRAZING AND  
DIFFUSION BONDING. W. R. Young and E. S. Jones.  
Period covered: 1 Nov. 1961-30 Nov. 1962.  
General Electric Co., Evendale, Ohio, Final Report,  
ASD-TDR-63-88. Jan. 1963. 105p. illus. Contract:  
AF 33(616)-7484, Proj. 7351, Task 735101. 4 refs.  
A63-4419.

Braze alloys were designed and evaluated for metallurgical compatibility with Cb-base materials, transition temperature, and high temperature strength of brazed joints. Four braze alloys: AS-540 (60V-30Cb-10Ti), AS-541 (60V-30Cb-10Ti-.2C), AS-546 (60V-30Cb-10Zr), and AS-547 (59V-29Cb-10Zr-2Si), have been identified which exhibited excellent metallurgical compatibility and high temperature strength. Low temperature ductility of F-48 brazements, however, was decreased somewhat as a result of the brazing process. The possibility of, and important variables in achieving brazed joints possessing failure temperatures above the original brazing temperatures were investigated. Braze alloys containing appreciable additions of melting point depressing elements were generally found unsuitable due to excessive brittleness. An increase in failure temperature of 500°F, however, could be attained with more ductile and compatible braze alloys. Applied stress during testing was the most critical parameter influencing this failure temperature. Although only relatively minor efforts were directed to the brazing of unalloyed tungsten, a braze alloy, AS-517 (Cb-2.2B), has been identified which produced tungsten brazements of excellent strength at 2500 and 3000°F without significant adverse effect on low-temperature ductility. The characteristics of diffusion bonding refractory alloys to grossly dissimilar materials have been investigated by metallographic examination, post-bonding thermal exposure, and bonding shear strength determination. As may be expected from their unfavorable differences in atomic size, electronegativity and/or crystal structure, diffusion-bonded joints between the bcc refractory alloys and the Fe-, Ni-, and Co-

2-516 (Continued)

base alloys were characterized by intermetallic formation at the bonding interface. Although these joints were ductility limited at low temperatures, examples were found which exhibited sufficient plastic flow and, hence, useful strength at elevated temperatures. It has been shown that the extent of intermetallic formation may in some cases be restricted by the use of an intermetallic material as a diffusion barrier. (Author)

2-517 MANUFACTURING METHODS AND DESIGN PROCEDURES FOR BRAZED REFRACTORY METAL HONEYCOMB SANDWICH PANELS. J. W. McCown and A. Norton. Interim Engineering Progress Report, 1 Sept. -1 Dec. 1962. Martin Marietta Corp., Baltimore, Rept. no. IR 7-937(IV); ER 12763. 113p. illus. Contract: AF 33(657)-7276, ASD Proj. 7-937. 3 refs. A63-30.

The purpose of this program is to establish design criteria and to develop manufacturing methods for brazed refractory metal honeycomb sandwich panels. The panels developed in this program are to be suitable for application on aerospace vehicles as either hot structures or radiant heat shields. This report covers a part of Phase II, consisting of the fabrication and experimental evaluation of the honeycomb sandwich panels. TZM (Mo-0.5Ti-0.08Zr) molybdenum and D-36 (Cb-10Ti-5Zr) columbium alloys were chosen for use on the program. Pfautler PFR-6 oxidation protection coating for TZM and Thompson-Ramo-Wooldridge Cr-Ti-Si coating for D-36 were selected to protect the panels during high temperature testing. Special tools and procedures were developed to fabricate the honeycomb core. All molybdenum welding is being accomplished by electron beam techniques. A 4200°F cold wall vacuum furnace is being used to braze the honeycomb test panels. A quartz-lamp facility will be used to heat the panels for structural testing. The heat-shield panels will be tested in a 14-inch oxygen-propane hot-gas facility. A 3500°F cold wall vacuum test chamber will be used to determine material and honeycomb properties.

2-518 STATUS REPORT NO. 2 ON DEPARTMENT OF DEFENSE REFRACTORY METALS SHEET-ROLLING PROGRAM. H. R. Ogden. Battelle Memorial Inst., Columbus, Defense Metals Information Center, Rept. no. 176. 15 Oct. 1962. 37p. illus. Contract: AF 33(616)-7747, Proj. 2(8-8975). 2 refs. A62-10756.

During this report period, emphasis in the many programs involved has been on developing optimum sheet fabrication procedures. The columbium program is nearing completion of laboratory rolling studies, and a single composition for larger scale rolling studies will be selected in the near future. In the molybdenum program, it has been shown that true hot

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forging of billets to sheet bar results in higher recrystallization temperatures of TZM and Mo-0.5Ti sheet than are obtained when normal forging temperatures are used. The tantalum program is in the early stages of ingot production and primary breakdown fabrication of the Ta-30Cb-7.5V alloy. Three methods of fabricating tungsten sheet are being investigated: rolling of powder-metallurgy billets, fabrication of arc-melted ingots, and flturning of cylindrical blanks. Properties obtained on both powder-metallurgy and arc-melted tungsten sheet compare very favorably.

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1. Report on Refractory Metals Sheet-Rolling Panel Activities, Report No. MAB-172-M, Materials Advisory Board, National Academy of Sciences, National Research Council, Washington 25, D. C. (May 22, 1961).
2. H. R. Ogden, "Status Report No. 1 on Department of Defense Refractory Metals Sheet-Rolling Program", DMIC Report 161 (November 2, 1961).

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